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INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF ORAL AND MAXILLOFACIAL SURGERY

COMPARISON OF IMPLANT-LIKE CYLINDRICAL RODS WITH FOUR DIFFERENT SURGICAL IMPLANT GUIDES BY 3D IMAGING METHODS

DOCTOR OF PHILOSOPHY THESIS

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APPROVAL

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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.

20.12.2022

Berk Tolonay

DEDICATION

I dedicate my thesis to my lovely son Doruk…

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
PET	Polyethylene Terephthalate
PETG	Polyethylene Terephthalate Glycol-Modified
PLA	Polylactic Acid
PLLA	Poly-L-Lactide
2D	Two-Dimensional
3D	Three-Dimensional
SLA	Stereolithography
SLS	Selective Laser Sintering
FDM	Fused Deposition Modelling
UV	Ultraviolet
CAD	Computer-Aided Design
CT	Computed Tomography
CBCT	Cone-beam Computed Tomography
FOV	Field of View
HU	Hounsfield Unit
DICOM	Digital Imaging and Communications in Medicine
STL	Standard Triangle Language

ABSTRACT

Tolonay B. (2022). Comparison of implant-like cylindrical rods with four different surgical implant guides by 3D imaging methods. Yeditepe University, Institute of Health Sciences, Department of Oral and Maxillofacial Surgery, Ph. D Thesis, Istanbul.

The purpose of implant treatment is to replace a missing tooth root. Implant placement is a surgical procedure. Many factors can affect implant success but one of them is the place of the implant which is also related with the experience of the operator. Eliminating surgical discomfort for the patient and misplacing possibility for the operators implant application guides are used world-wide. Guides are made of resin already. The aim of this study is to compare three filament-based materials and resin as a choice of material in guide production. In order to do that four main test groups are designed which are ABS, PET, PLA, and Resin. Three subgroups with 2 cm, 5 cm and 10 cm edge squares were created representing single crown, bridge restoration and totally edentulous mouth, respectively. Each subgroup has 10 samples and there are a total number of 120 samples. Linear deviations at the top and the apex of the implant and angular changes of the implants were observed. ABS, PET, and PLA were supplied from BASF 3D Printing Solutions GmbH and printed in Creality CR-10 v3. Resin guides were provided by Straumann. Each test subject was drilled by implant driver at 500 rpm 20 N/cm torque with irrigation. A pin (1,3mm in diameter and 27,95 mm in length) was placed into the socket scanned with NewTom CT. Statistical analyses were performed with NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) software. The results were evaluated at the significance level of $p<0.05$ and $p<0.01$. Best results were received in 10 cm group in linear and angular deviations. 2 cm groups are better in linear and angular deviations than 5 cm, but the difference was not statistically significant. There were no statistically significant difference in the same size between different materials. PET generally gave better scores than the others while ABS did the worse.

Key Words: Dental implant, implant guide, resin printers, fdm printers.

ÖZET

Tolonay B. (2022). Dört farklı cerrahi implant klavuzu ile yerleştirilen implant benzeri silindirik çubukların 3B görüntüleme yöntemi ile karşılaştırılması. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Ağız, Diş ve Çene Cerrahisi Ana Bilim Dalı, Doktora Tezi, İstanbul.

Dental implant tedavisinin amacı eksik bir diş kökünü tamamlamaktır. Dental implant yerleştirmek cerrahi bir prosedürdür. Dental implantların başarısını pek çok etken değiştirebilir ama bu etkenlerden biri implantın konumudur ve cerrahın tecrübesi ile de ilişkilidir. Hastanın konforunu arttırmak ve cerrahın yanlış konumlandırma ihtimalini azaltmak için implant uygulama klavuzları dünya çapında kullanılır. Klavuzlar günümüzde reçine ile üretilmektedir. Bu çalışmanın amacı üç farklı filament şeklinde üretilmiş malzeme ile reçineyi klavuz üretim malzemesi olarak kıyaslamaktır. Bu çalışmayı yapmak için ABS, PET, PLA ve Reçine olmak üzere dört farklı ana deney grubu vardır. 2 cm, 5 cm ve 10 cm olarak sırasıyla tek kuron, köprü restorasyonu ve total dişsiz bir ağızı temsil eden farklı boyutlarda 3 alt grup vardır. Her alt grup için 10 adet toplamda 120 adet deney düzeneği vardır. İmplantın boyun ve apeks kısmında çizgisel sapmaya gövdesinde ise açısal sapmaya bakılmıştır. ABS, PET ve PLA filamentler BASF 3D Printing Solutions GmbH firmasından temin edilmiş ve Creality CR-10 v3 yazıcısı kullanılarak yazılmıştır. Reçine klavuzlar Straumann tarafından temin edilmiştir. Her deney düzeneği implant angldruvası ile 500 rpm hızda ve 20 N/cm torkta sıvı irrigasyon ile frezlenmiştir. Her düzenek frezlendikten sonra boşluklara pin yerleştirilmiş ve NewTom CT ile görüntülenmiştir. İstatistiksel analizler NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) yazılımı ile yapılmıştır. Sonuçlar $p<0.05$ ve $p<0.01$ anlamlılık düzeyinde değerlendirilmiştir. Çizgisel sapma ve açı farklılığı konusunda istatistiksel olarak anlamlı ve en iyi sonuçlar boyut olarak 10 cm grubunda çıkmıştır. Bu anlamda 2 cm grubu 5 cm grubundan daha iyi sonuç vermesine rağmen çıkan farklar istatistiksel olarak anlamlı bulunmamıştır. Aynı boyutta farklı malzemelerin değerlendirilmesinde farklılıklar vardır ancak istatistiksel olarak anlamlılık yoktur. PET deneylerde daha iyi sonuçlar verirken en kötü sonuçlar ABS'de bulunmuştur.

Key Words: Dental implant, implant guide, resin printers, fdm printers.

1. INTRODUCTION

Dental implants are medical devices that interfaces with the bone to support prosthesis such as dentures, bridges, single crowns, or even facial prosthesis. They can be also used as orthodontic anchorage. Dental implants improve the patient's quality of life. It is not only about chewing food but also appearance, phonation, and self-confidence so mental health of the patient. Modern dental implants are based on a process called osseointegration (1). Dental implants mainly made of titanium because they are the materials that are known to prone to osseointegration.

Success or failure of the implant depends on many factors including systemic condition of the patient, wound care procedures or surgical procedures. Surgical procedures depend on mainly the operator. Anatomy of the bone should be considered well. Remaining bone volume or neighbor anatomical structures can make it difficult to place an implant.

In difficult cases digital imaging and digital planning is very important before the procedure. CT images allows the operator to evaluate the bone before the operation. This prevents explorative surgery and any unwilling situation. By evaluating the bone before surgery, operator can bring the devices or biomaterials needed.

Additive manufacturing is a production method and have usage in many fields. It is mainly used for prototyping, complex shape or small amount of production. It is commonly known as 3D printing. There are many methods and many materials that can be used in 3D printing. It can be industrial or household units. Products can be solid or flexible, tough, or fragile, heat resistant, colored, or clear. Raw material can be filament shaped or in a resin form depending on the printer type.

In dentistry, 3D printers are involved recently. Study models, temporary crowns, mockups, dentures, and surgical implant guides can be made in today's possibilities. 3D printers are getting smaller and faster. Materials variety increases and capabilities of 3D printers in dentistry are getting stronger.

Implant surgery guides has a lot benefits. In total edentulous it is sometimes difficult to determine the location of the implant. When multiple implants are present it can take a long time exploring and determining suitable implant location on alveolar crest with standard technique (2). Implant guides reduces the operation time, eliminates incision and flap exposure. As it is less invasive patient undergoes less post-operative morbidity and discomfort. This is an easier way for both clinician and patient. It also reduces post operative hemorrhage and trismus risk. It doesn’t increase the implant survival rate (3) but since it is flapless and bone blood supply is minimally damaged it can be said that long term success will be possibly high.

2. LITERATURE REVIEW

The recent technology, three-dimensional (3D) printing, has revolutionized engineering, product design, and manufacturing and holds big promise for doing the same for medicine. 3D printing makes it possible to create actual objects quickly from information contained in digital 3D models. 3D printing is also called additive manufacturing, solid free form fabrication, layered manufacturing or rapid prototyping (4).

In classic manufacturing, material is removed from a block often by milling. This is called subtractive technique. In the other hands 3D printers works as layers this is why it is called additive manufacturing (4).

2.1. Brief History of 3D Printing

3D printing idea comes from 1980s when Hull first invented stereolithography (SLA) (5). SLA works in UV light and photo-sensitive monomer principles. UV light is directed into a container which is full of photo-curable monomer and passes through a specific pattern. Areas that are exposed to UV are cured and creates a 2D cross-section of the desired design. Non-exposed monomer stays in the container as it is.

SLS (selective laser sintering) is another technique for manufacturing (6). SLS involves a laser source (i.e., carbon-dioxide) to fuse small glass, plastic, metal, or ceramic particles into a mass layer by layer. Since laser source is expensive and dangerous for home use, it is not popular in consumer level. The system consists of a laser source, scanning system, roller, powder supply platform and sintering platform. Powder molecules are fused under the influence of laser beam. When one layer is fused, sintering platform goes one step downwards. The process continues until the last layer. Movement of laser is controlled by a G-code as in FDM printers. After sintering is completed, unsintered powder is removed from the object and separated from the platform (7)

Fused deposition modelling (FDM) is also called fused filament fabrication defines a technique that thermoplastic filaments are placed one on another in a sequence on a building platform (6,8). Filaments are ejected from a nozzle in a semi-solid state through a path that creates a pattern of the objects one 2D cross-sectional slice. That process creates a layer. When printer finishes one layer, building platform goes downward or nozzle goes upward a step and makes a new layer over the existing one. CAD model is sliced into layers by a slicer software and a G-Code is created. G-code is a language that tells the printer where to move the nozzle and adjust the temperature and ejection speed of material (7).

2.2. Materials

A polymer can be naturally occurred and called biopolymer or can be synthesized and called non-biopolymer. In both condition polymers are made of repeating monomer units. Same monomers bond together to create long polymer chains.

Properties of monomers, numbers and chain configuration determines physical and chemical characteristics of polymers.

There are variety of materials that can be used in consumer filament-using 3D printers but three of them are more popular among others (9). These common 3D thermoplastics are PLA (Polylactic acid), PET (Polyethylene terephthalate) and ABS (Acrylonitrile butadiene styrene). Most of the consumer-level 3D printer are capable of using these materials. Both filaments and printers can easily be found in the market. They are used in engineering, architecture, prototyping etc.

All three materials have different physical and chemical properties. In routine use selecting material for a project requires trading off many different factors based on the use of the object, available materials, and cost. In our study reliability of these materials were evaluated in terms of shape and dimensions, in an implant placement simulation test.

2.2.1. PLA

Polylactic acid is a biopolymer. Monomer structure is lactic acid and correct definition is poly (lactic acid). Polylactic acid is first invented in 1930s by Wallace Carothers. It is not commercialized by 1950s because there were common petrochemicals such as nylon and neoprene. After oil embargoes in 1970s alternative materials quest had been set off and PLA had drawn attention by researchers. PLA can be produced from any starchy material. Corn is a common agricultural plant in USA and PLA is mainly made of corn starch. Lactic acid can directly be turned into PLA or can be exposed to lactide that looks like two lactic acid molecules stuck into together. Polymerization reaction left residual water and it is removed by vacuum or distillation afterwards (10).

PLA properties depends on composition recipe but besides composition PLA is a thermoplastic material. Thermoplastic means material melts above a certain temperature and turns into a solid form below that temperature (11).

PLA is biodegradable material (12). Under proper conditions PLA degrade into lactic acid monomer in a significant short time than petroleum-based polymers. PLA is also a biocompatible material (13,14). PLLA which is a L type derivation of lactide monomer of an essential PLA chain, is commonly used in fixation applications in the body. Breakdown may take up to 24 months (15) so this feature makes it a good choice for using as a frame material and prevents a second surgery to remove the material (16).

2.2.2. ABS

ABS is a tough, hard, and heat-resistant material. These properties make it more favourable than other polymers when a heavy-duty is needed. ABS's useful working temperature range varies from -20 to 80 °C (17). Its use widely spreads from house appliances to car interior parts and it is also what LEGOs are made of (18).

ABS is a combination of styrene-acrylonitrile copolymer with butadiene rubber. Acrylonitrile parts attaches together, binds the neighbour chains, and gives its strength. Acrylonitrile parts also gives the properties of fatigue and chemical resistance and increase heat deflection temperature (19). Styrene gives the material a shiny look and eases processing. Ductility and resilience comes from butadine (20).

In 3D printing ABS is a common filament. It is cheap, durable and it is possible to smooth the surface texture by different ways (filling, sanding, chemical smoothing etc.). However, printing ABS plastic is a bit tricky. When the material is extracted from nozzle it faces with a heat difference. When ABS is exposed this temperature difference, it shrinks. In order to prevent this, a closure around the printer -which is usually called a heat chamber- should be built. The first layer adhesion is essential so if a heat chamber is not enough, plastic adhesives for printing surface should be considered.

2.2.3. PET

Polyethylene terephthalate or in better words poly(ethylene terephthalate) is the most common material in thermoplastics category (21). Ethylene terephthalate is the monomer and repeating units form($C_{10}H_8O_4$)PET. PET is first invented and patented by John Rex Whinfield, James Tennant Dickson in 1941 (22). The most known form of PET is water bottles and it is invented by Nathaniel Wyeth in 1973 and patented by DuPont (23).

PET can be copolymerized with diacids or diols to optimize properties for certain uses (24). Common one is replacing ethylene glycol with cyclohexanedimethanol. This modification effects crystallization and lowers temperature of melting point. This end result is named as PETG, and it is the derivation that was used in this study. PETG is a clear amorphous thermoplastic but can be coloured during processing (25,26).

2.2.4. Resin

In 3D printing, resin is light-activated and also called photopolymer. This polymer reacts to light and changes its properties. Light is usually in ultraviolet region of electromagnetic spectrum (27). 3D printer resin is usually consists of monomers, oligomers and photoinitiators. When resin is exposed to UV light, cross-linking chains starts to appear between structural elements. This process results in hardening of the material and this is called curing (28). During this process, a volume shrinkage happens. Resins in 3D printing have monomers including acrylates and methacrylates to reduce shrinkage (29).

2.3. Digital Dentistry

Dentistry is a branch of medicine which is diagnosis and treatment is always dependent mainly on doctor’s experience and capability. Diagnosis begins with understanding and evaluation the problem that the patient complains. Doctor should take whole history completely and carefully. Examination of the visual and apparent indications are important but most of the time it is insufficient. X-Ray imaging takes a great role at this point.

The first dental x-ray was taken just 14 days after the announcement of roentgen rays. This dental x-ray was taken by Friedrich Otto Walkhoff in 1895 (30). Walkhoff put a photographic glass plate between his own tooth and tongue and exposed himself 25 minutes to acquire an image. In 1986 Walkhoff established a dental imaging laboratory with Fritz Giesel. Laboratory worked many years but in 1927 Fritz Giesel died of metastatic carcinoma caused by extreme radiation exposure to his hands (31).

After many years passed with 2D images, a British engineer Sir Godfrey Hounsfield developed Computed Tomography (CT) in the late 1960s (32). In his method, single X-ray images of axial images composes a main digital 3D mass in computer.

In 1990's two scientist in different countries and unaware of each other developed Cone Beam Computed Tomography (CBCT) for dental usage (33). First commercial CBCT unit (New Tom 9000) introduced in 1996 by company Quantitative Radiology (34).

3D imaging methods rather than 2D not only eased the examination of patients but also marked an era in treatment options. Guided implant surgery -which is our topic in this study- is one of the treatments that can be possible with 3D imaging.

Human jaws have three dimensions as any physical object. In physical and geometrical manner only two dimensions can be seen and can be calculated. In order to see the third-dimension observer should look at in a different angle. Basic orthopantogram images show patient's jaws in two dimensions. In order to see the third dimension -in other words the width of the bone- operator have to perform an explorative surgery or can take a 3D image to observe the bone conservatively.

Viewing the bones in three dimensions before the surgery has many advantages. It is used to be done with printed clear implant measurement sheets onto printed x-rays or done with software but again in 2D in the same manner. Operator can decide implant diameter and length by taking into consideration of anatomical structures and derivations by 3D images (35). These may be inferior alveolar nerve channel, mental foramen, maxillary sinus, or it can be a tooth socket thin wall, narrowed space or tipped root apexes or there may be defects in the bone.

This era is the time that technological developments of radiology and engineering meets together. Everything designed in printers can be manufactured into solid objects.

Production speed increases and costs are reduced (36). A specialist can evaluate patient's CBCT images and plan implant positions via a computer software in minutes. Then the software designs a placement guide stent for planned implants. A stent takes roughly half an hour to be made. A guide stent is making it possible a flapless surgery. This results in a faster and less invasive surgery. The less is soft tissue damaged the more bone keeps blood flow from periosteum and this results in minimum or no bone loss.

Another advantage of using 3D treatment planning is skipping impression phase. Patients' occlusion and all other records are being saved in the software. It allows the practitioner to design and produce the restoration even immediately. Because everything is planned and designed before, patient can leave with temporary restorations after surgery.

Resin printing is a standard in implant guide production. Many implant productors and dental technicians use resin and resin printers. Resin is polymerised by a light as it is mentioned before. After the polymerisation and production of the object finished, there are uncured resin left on the object. To use the object, it must be cleaned. There are a couple of solutions in the market but the most effective and available one is isopropyl alcohol. Object can be washed by hand, or an ultrasonic bath can be used for more effective clean. After this cleaning, object should be cured for one more time by a UV light. This whole procedure is done by an operator.

Unlike resin printers, FDM printers does not need a further process after printer finishes object. This means there is no need for additional device or solution. Its final physical and chemical properties are ready to use. Depending on the object it saves time. Filaments are generally cheaper than resins in the same amount of volume. Some of the filaments are recyclable so it makes them more eco-friendly.

These good points can be advantageous in clinic workflow. This is the starting point of the idea of using FDM printers in dentistry. The aim of this study is to evaluate resin and FDM printers in implant dentistry.

There are many implant companies and individual technicians that can provide surgical guide in the market. Nobel, Astra, Bilim, Megagen, Osstem are just a couple of known brands. Straumann is one of the guides providing implant companies and has a good background in dental implantology.

Straumann surgical guides are made of light activated resin. The components are acrylic resin, urethane dimethacrylate (UDMA), 2,2-bis (acryloyloxymethyl) butyl acrylate; trimethylolpropane triacrylate and Diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide (TPO).

In this study it is aimed to compare the common implant guide production method (Resin), with alternative technique and materials (FDM – ABS, PET, PLA). Straumann has a complete solution from 3D printer, curing station, resin to drills, sleeves. This was the reason of including Straumann to this study. FDM printer was Creality CR-10 v3. This was a mid-range printer and capable of all of the test filaments. The hypothesis was resin, and the other 3 materials show similar results.

Apart from resin, titanium is used in recent studies in guide production. It is carved from a big titanium disk like in the metal-supported crown production. It is relatively expensive that the other methods and needs more study.

3. MATERIAL AND METHOD

In this study implant planning and placing was evaluated. There were 4 groups of different materials. First group was ABS and sample size was n=40, second group was PET and sample size n=40, third group was PLA and sample size n=40, fourth group was Resin and sample size is n=40.

A test setup was designed to measure deviations between groups. In order to calculate linear and angular deviations, geometrical shape was chosen. Three subgroups were made according to size of square prisms that were designed in SolidWorks computer software. First one has 2 cm edge and represents a single missing tooth. Second one has 5 cm edge and last one has 10 cm edge represents a bridge restoration and total edentulous mouth, respectively. Each size has 2 cm height. A fixation pin was used as an implant in this study. This pin was supplied by Straumann. The reason for choosing this pin is it has its own drill and a sleeve mechanism like in implant guides. So, it is easy to repeat the process and also it has less refractions in CT than an implant itself. Position of the pin was also designed in SolidWorks software. Each pin was placed to the centre of transversal plane of test block. The test blocks are radiolucent in CT. In order to navigate and determine sagittal plane, three metal balls were placed in every test block in the same position. These metal balls are also defined in computer design, and they are used to place every test object in the exact same place while making measurements. Test blocks are produced with Anycubic clear resin.

The shapes for the test blocks were chosen rectangular prism. It was easy to find the centre of the shape, calculate measurement and repeat the test in a geometrical shape. Test blocks were radiolucent. When the pin was placed in the block, reference points were needed to compare the position of the pin. For this purpose, metal balls were placed into test blocks. To calculate angular and linear deviations, a transversal plane section is needed. A plane requires minimum of 3 points. 3 points was sufficient for this test. 4 points complicates to determine side walls of the test block.

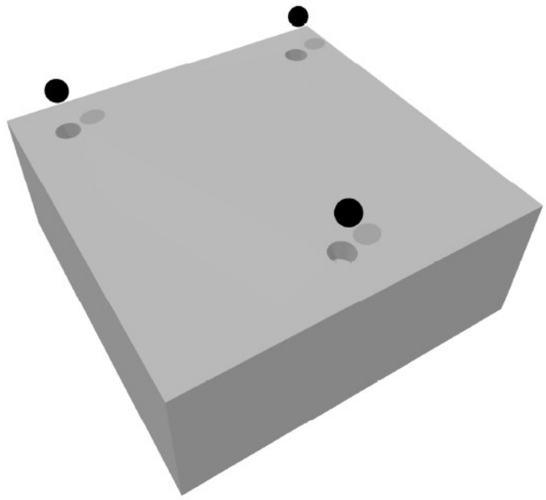

Figure 3.1. Test Block and Metal Balls

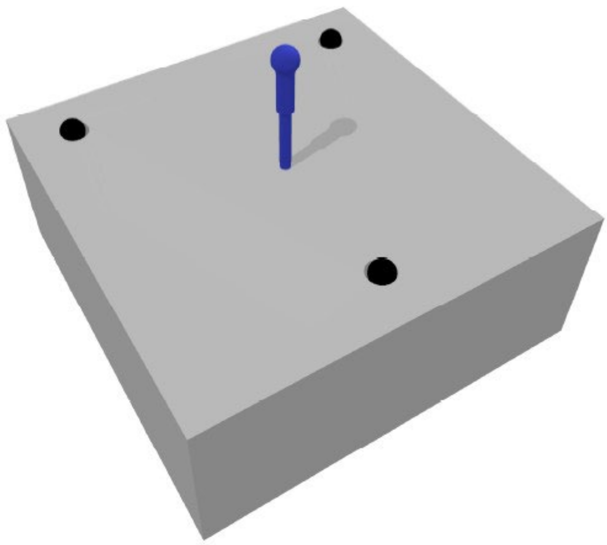

Figure 3.2. Test Block and Pin

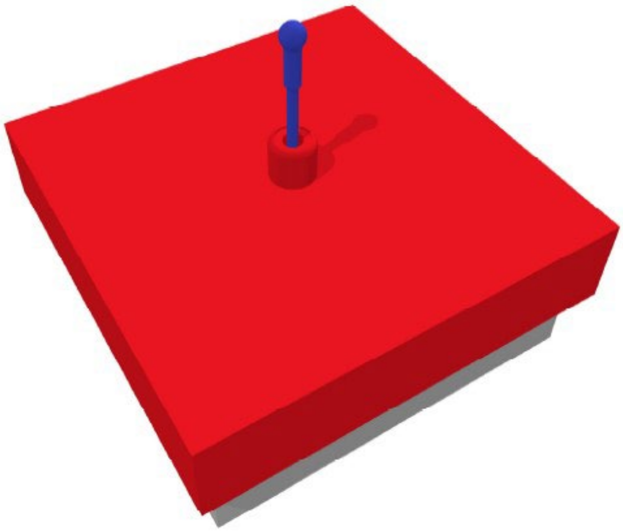

Figure 3.3. Test Block, Guide and Pin

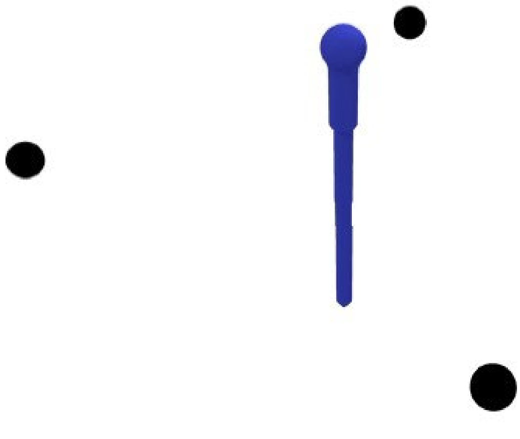

Figure 3.4. Metal Balls and Pin

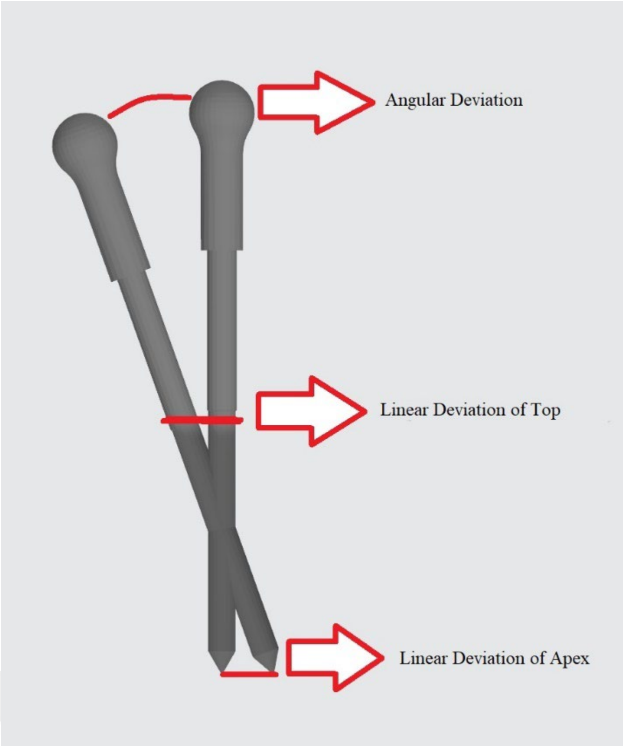

Figure 3.5. Definition of Linear and Angular Deviations

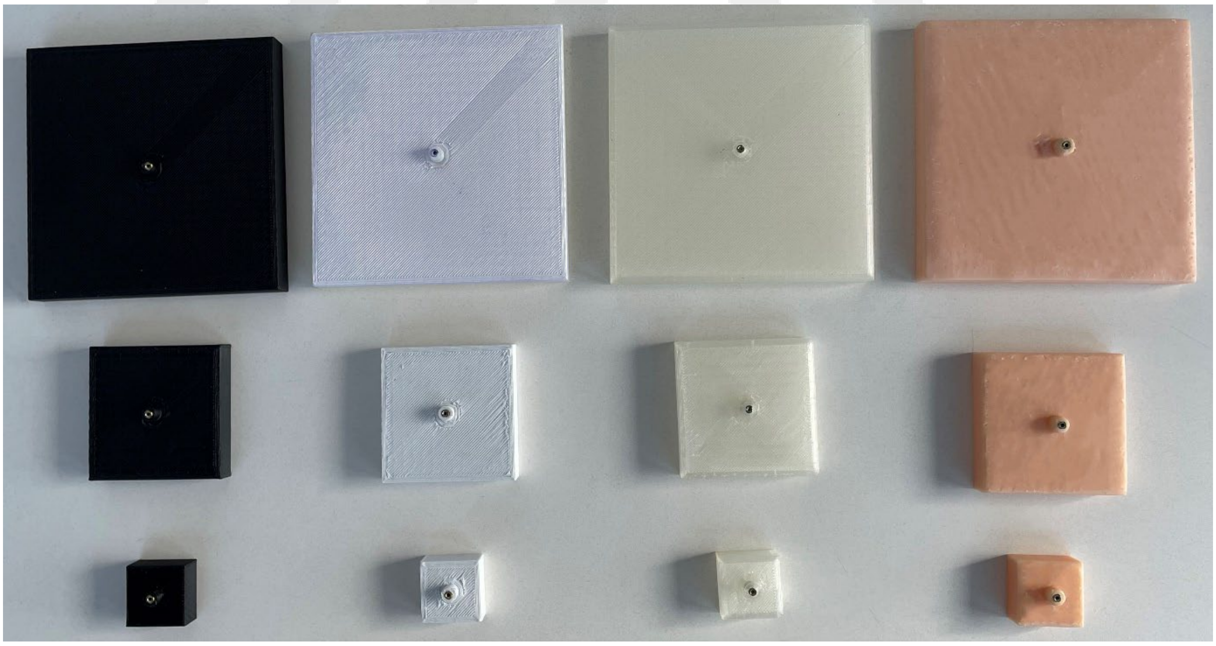

Figure 3.6. Each size and material of guide materials.

From left to right ABS, PET, PLA, and Resin. From top to bottom 10 cm, 5 cm, and 2 cm guides.

Figure 3.7. Anycubic clear resin

Printers that create blocks are Anycubic Mono SE and Anycubic Mono X. Their edges are then measured with digital calliper and approved that they have no volumetric differences.

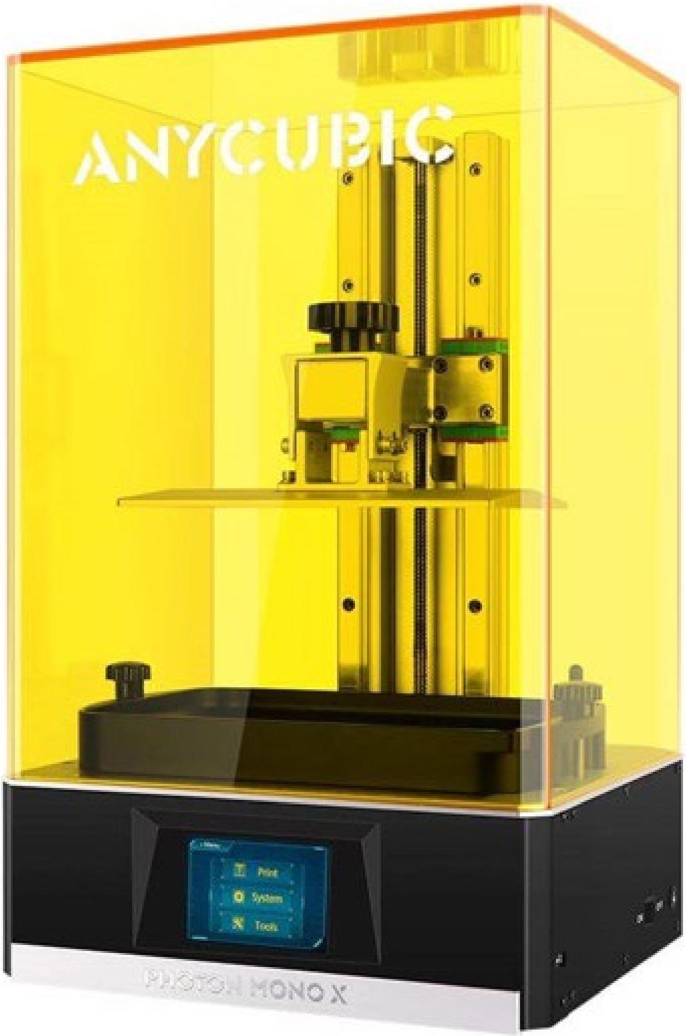

Figure 3.8. Anycubic MONO X

Figure 3.9. Anycubic MONO SE

Control groups were designed in computer using SolidWorks. It represents the implant position that is wanted to be placed. Resin is one of test groups. Other three test groups were ABS, PET, and PLA filaments. The idea here is to compare filaments with each other, with resin and also compare resin with the control group as well.

3.1. Straumann Cares P30

For resin guides, printer choice is Straumann Cares P30. It is a dental-related product. This means it has practical features for dental profession. Its software such as coDiagnostiX and auxiliary devices are making it practical and successful.

Technical Specifications	
Resin compatibility	DLP, 385 nm
Building area	130 x 75 mm
Layer thickness	Standard: 50 and 100 µm (finest 0.5 µm)
Max. part height	110 mm
Resolution	1920 x 1080 px

Table 3.1. Technical specifications of Straumann Cares P30

This printer uses many resins for many applications such as temporary crowns, dentures etc. In this study the resin choice is P pro Surgical Guide. It is DLP compatible and polymerizes at 385 nm wavelength. Its recommended layer thickness is 100 µm.

3.2. Creality CR-10 v3

For filaments, the printer choice was Creality CR-10 v3. The reason for using that printer is it is one of the most developed printers in consumer class, but it still has a reasonable price. It also has the ability of printing all of the test filaments, so there was no need to use another printer to print ABS. Thus, one of the variables was eliminated. PLA and PET can be printed without any additions. In order to print ABS, there must be an enclosure. It is called heat chamber and as understood its name it keeps the temperature hot inside. As mentioned in introduction, ABS is sensitive to heat changes and prone to warp.

Figure 3.10. Creality CR-10 v3

Filaments used in the test is BASF Forward AM branded. They are well documented filaments, has all mechanical datas and it has a standardised, high quality production. Different colors for each filament was chosen to distinguish them .

3.3. Basf Forward PLA

PLA was chosen in transparent colour. PLA is one of the easiest filaments to print. It does not need any heat chamber or any adhesive to printing plate. Ultrafuse® PLA is Poly-Lactic-Acid, a biodegradable polymer with a low melting point. It is an easy material to print with and Ultrafuse® PLA gives a smooth printing result. When properly cooled, PLA has a higher maximum printing speed, lower layer heights, and sharper printed corners. Combining this with low warping of the print makes it a popular plastic for makers, prosumers, and schools.

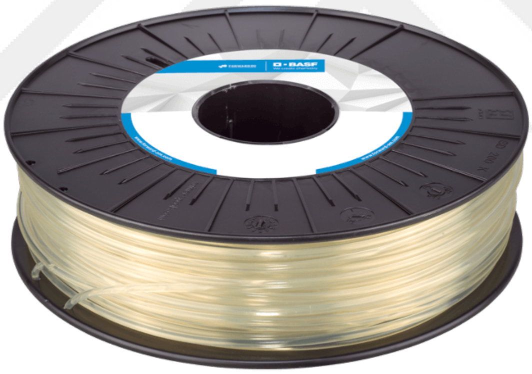

Figure 3.11. BASF PLA filament

3.4. Basf Forward PET

The PET filament was white in colour. It is relatively easy to print PET. It does not need a heat chamber as ABS, but the printing table should be heated. It does not warp while cooling but increased print speeds give better smooth results. Ultrafuse® PET is made from a premium, food approved PET (Polyethylene terephthalate). PET is widely used to produce food and beverage containers and bottles. This high-quality filament will give you outstanding printing results: good layer adhesion, high resolution and easy to manage. It has a natural transparent, smooth look. Ultrafuse PET can be 100% recycled.

Figure 3.12. BASF PET filament

3.5. Basf Forward ABS

The last filament was ABS with black colour. It is the most complicated one to print. It shrinks when it is cooling. Heat chamber around the printer prevents sudden heat changes so the model can keep its original shape until it is finished. Ultrafuse ABS is the second most used 3D printing material. Ultrafuse ABS is strong, flexible with high-temperature resistance. It is a preferred plastic for engineers and professional applications. ABS can be smoothened with acetone and sprayed. To make a proper 3D print with ABS you most probably will need a heated print bed.

Figure 3.13. BASF ABS filament

After blocks and guides are ready, each guide is placed onto block and pressed with a hydraulic press to be sure that it is properly fitted.

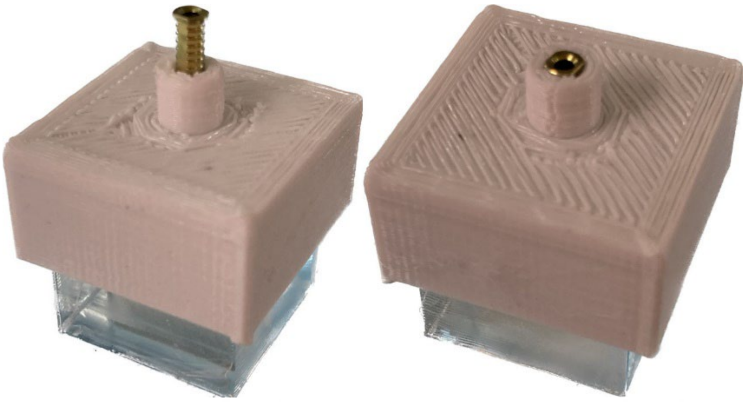

Figure 3.14. Sleeve Insertion

Pin places in the blocks were prepared with its own drill by an implant driver. There was no speed and torque advice for this drill, so it was decided to work on low speed (30rpm) and relatively high torque (50N) with isotonic irrigation. The hole was irrigated with a needle afterwards to clean all debris. This prevents any misplacement of the pin.

Figure 3.15. Block Drilling

Figure 3.16. T-Sleeve for Template Fixation Pin 034.283

Figure 3.17. Drill for Template Fixation Pin 034.284

Figure 3.18. Template Fixation Pin 034.282

All 120 samples were prepared with the same method. After drilling, all guides were removed from blocks.

Each test sample was scanned by CT (NewTom 5G, Cefla Group, Imola, Italy). Maximum output current was 110 kV and 20 mA. There are several fields of view (FOV) options in the device. The best for this test was 12x8. It is because the images can be taken at maximum resolution possible in the same FOV. So, a derivative was standardized. Images were taken in denture scan option. Raw data that first collected was than reconstructed in 200 µm isotropic voxel. DICOM output was made by sequence of original axial images. Resolution of final images were 614x614 pixels.

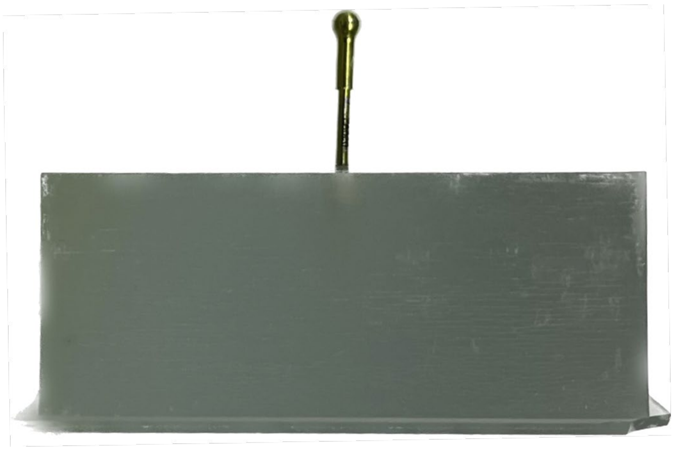

Figure 3.19. Pin placed to the block

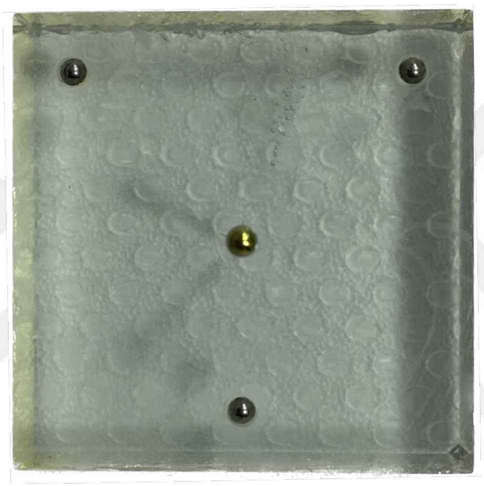

Figure 3.20. Pin placed to the block

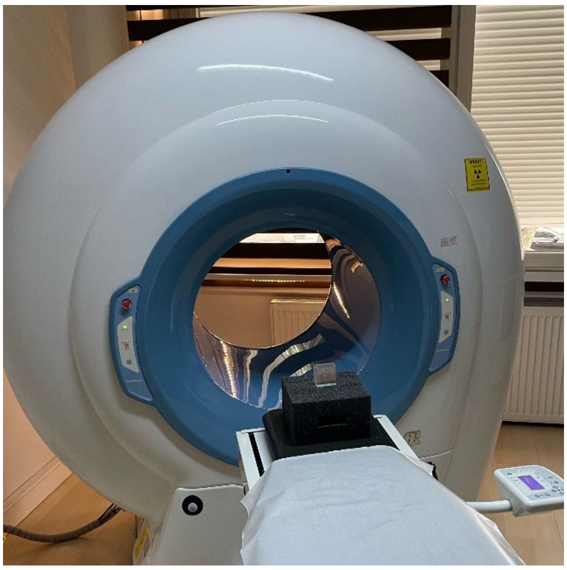

Figure 3.21. Test Block Imaging

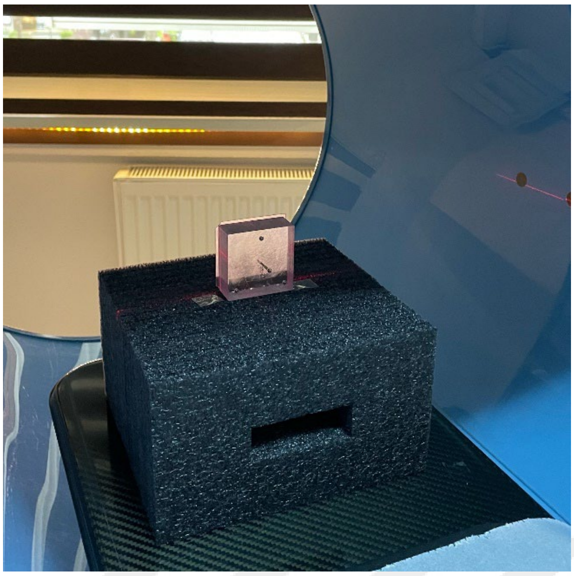

Figure 3.22. Test Block Imaging

CT images collected as DICOM data. DICOM is a 3D data, but it is not recognised by CAD software. To perform tests about our study, DICOM is needed to be converted into a stereolithography CAD format. Most common and easy-to-use format in this type is STL. STL has several backronyms, but it is best known as Standard Triangle Language. As it can be understood from name, it describes the surface of masses as connected triangles. Once data is in STL format it is possible to calculate distance and angular differences.

Figure 3.23. Collecting DICOM Data

First DICOM data was imported into Nemo Studio (2021 Fall) software. Nemo studio is an aligner designer, orthodontic software. It can superpose digital mouth models and CT data. This software is able to convert DICOM images to STL data as well. Each sample has different refractions and radiation density. Hounsfield Unit (HU) was calculated for each individual sample. Metal balls were served as reference. They were 3mm wide in radius so by changing HU value they were arranged 3 mm radius in digital.

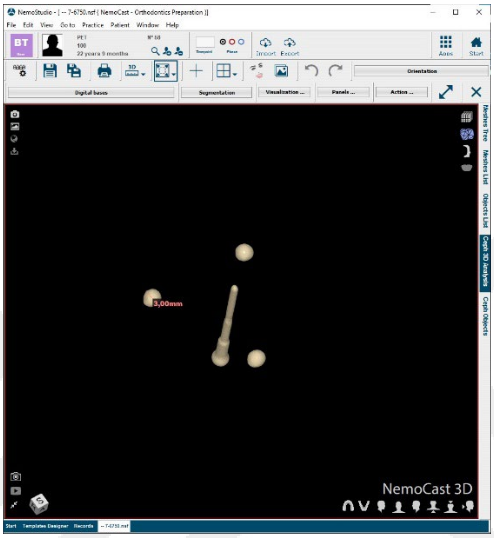

Figure 3.24. Nemo DICOM to STL Conversation

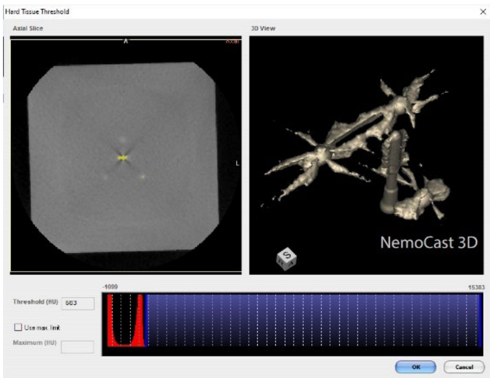

Figure 3.25. Nemo DICOM to STL Conversation

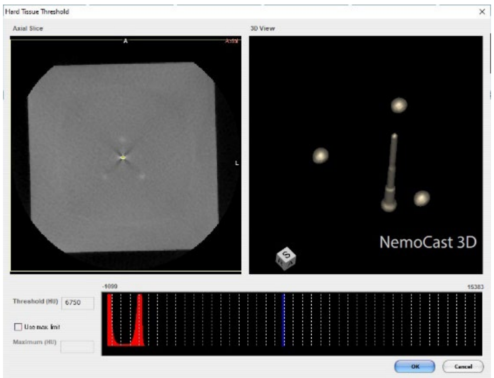

Figure 3.26.Nemo DICOM to STL Conversation

Control group was already in STL format. When test groups were converted into STL, they were not aligned. Three metal balls in test groups serves this alignment purpose with the ones in control group models. In order to centre the test groups, Exocad 3.0 software was used. This software is normally having many features like crown or dentures design, but it was only used to align models in coordinate space.

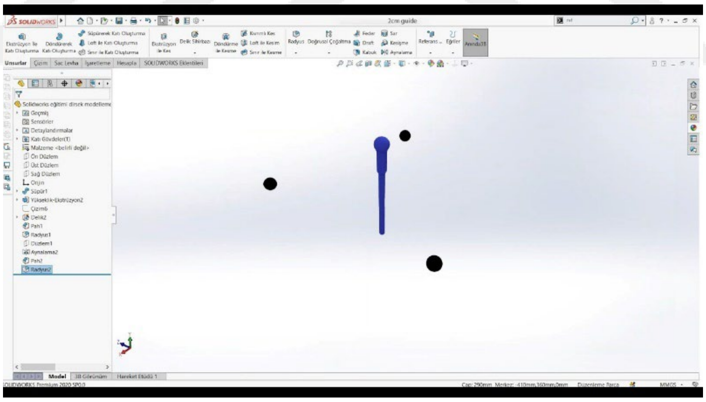

Figure 3.27. Control Group Design in SolidWorks

Once everything was aligned in coordinate space, each sample was imported and control group into 3Shape Viewer software one by one. 3Shape Viewer is able to open many STL files at the same time. It can cross dissect models and can give metric distance outcomes. Linear deviation was measured in the neck and the apex region of the pin. These two values are in millimetric scale. With these two values then the angular deviations were calculated for each pin. All data were collected in an excel table.

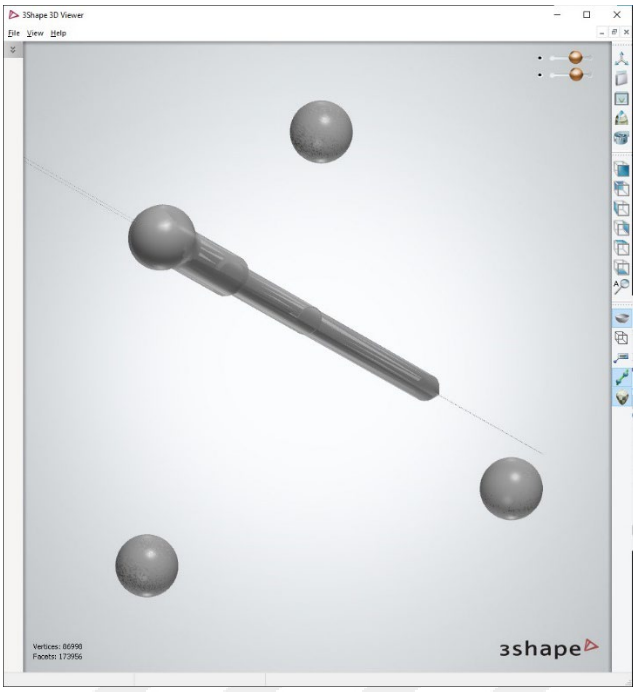

Figure 3.28. Superposing Control and Test STL image

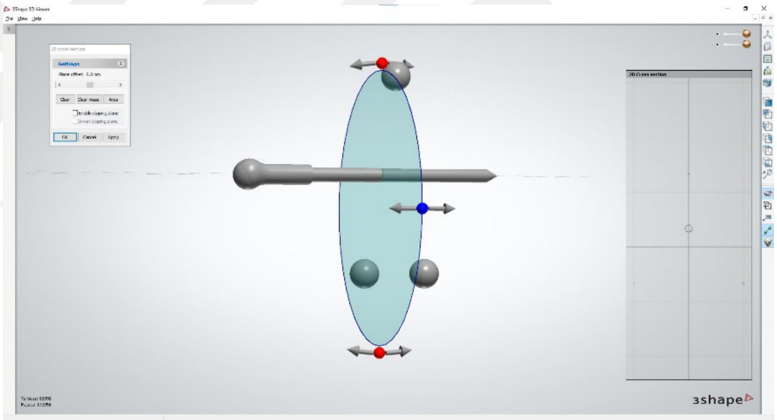

Figure 3.29. Measuring Linear Deviations

3.6. Statistical Analysis

The data were analysed using the NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) software. Study data was evaluated using Shapiro-Wilk test. Additional methods such as mean, standard deviation, median, frequency, ratio, minimum and maximum were also used. Quantitative data was compared with Kruskall-Wallis test for three and above numbers of groups, with Mann-Whitney U in paired groups. If $p<0.01$ and $p<0.05$, the difference was considered significant.

4. RESULTS

4.1. Linear Deviation at the Top of the Pin

Top deviation value shows statistically significant difference between groups.

Table 4.1. Comparison of top linear values deviation according to the dimensions of the groups

TOP		n	Mean±Sd	Min-Max (Median)	p
2 cm	ABS	10	0,12±0,03	0,08-0,16 (0,12)	0,001**
	PET	10	0,13±0,04	0,05-0,18 (0,14)	
	PLA	10	0,15±0,04	0,1-0,22 (0,14)	
	Resin	10	0,16±0,06	0,11-0,29 (0,14)	
5 cm	ABS	10	0,29±0,12	0,1-0,48 (0,3)	
	PET	10	0,16±0,06	0,1-0,25 (0,17)	
	PLA	10	0,25±0,31	0,09-1,13 (0,16)	
	Resin	10	0,23±0,42	0,03-1,4 (0,1)	
10 cm	ABS	10	0,18±0,22	0-0,62 (0,06)	
	PET	10	0,04±0,02	0,01-0,07 (0,04)	
	PLA	10	0,06±0,03	0,03-0,11 (0,07)	
	Resin	10	0,13±0,24	0,01-0,77 (0,04)	

Kruskall Wallis Test *p<0,05 **p<0,01

Table 4.2. Comparison of top linear values according to the material of the groups

TOP		n	Mean±Sd	Min-Max (Median)	p
ABS	**2 cm**	10	0,12±0,03	0,08-0,16 (0,12)	**0,021***
	5 cm	10	0,29±0,12	0,1-0,48 (0,3)	
	10 cm	10	0,18±0,22	0-0,62 (0,06)	
PET	**2 cm**	10	0,13±0,04	0,05-0,18 (0,14)	**0,001****
	5 cm	10	0,16±0,06	0,1-0,25 (0,17)	
	10 cm	10	0,04±0,02	0,01-0,07 (0,04)	
PLA	**2 cm**	10	0,15±0,04	0,1-0,22 (0,14)	**0,001****
	5 cm	10	0,25±0,31	0,09-1,13 (0,16)	
	10 cm	10	0,06±0,03	0,03-0,11 (0,07)	
Resin	**2 cm**	10	0,16±0,06	0,11-0,29 (0,14)	**0,025***
	5 cm	10	0,23±0,42	0,03-1,4 (0,1)	
	10 cm	10	0,13±0,24	0,01-0,77 (0,04)	

Kruskall Wallis Test *p<0,05 **p<0,01

There were no statistically significant differences in 2 cm groups. ABS-2, PET-2, PLA-2, Resin-2 have lower deviations than ABS-5 but, there were no significant difference when compared with the other 5 cm groups. All the 2 cm examples have higher deviation than 10 cm groups. ABS-5 has higher deviation than PET-5 and Resin-5 but there is no significant difference with PLA-5. ABS-5 has higher deviation than PET-10, PLA-10 and Resin-10 but has no significant difference than ABS-10. PET-5 and PLA-5 both have higher deviations than PET-10, PLA-10, and Resin-10. Resin-5 has higher deviation than PET-10.

PET-10, PLA-10 and Resin-10 has statistically lower deviations than any other groups in any sizes. ABS-10 has higher deviation than other 10 cm subjects but there were no statistically significant deviation. ABS-2, PET-2, PLA-2, and Resin-2 have lower deviations than all 5 cm groups but there is only statistically significant difference between ABS-5 ones.

This result shows us 10 cm has better accuracy at the top of the implant. 2 cm has better results than 5 cm but there is no statistically significant difference. PET has lowest and ABS has highest deviations overall, but only statistically significant difference is between ABS-5 and PET-5 Resin-5. Other differences are not statistically significant.

4.2. Linear Deviation at the Apex of the Pin

Apex deviation value shows statistically significant difference between groups.

Table 4.3. Comparison of apex linear values according to the dimensions of the groups

APEX		n	Mean±Sd	Min-Max (Median)	p
2 cm	ABS	10	0,18±0,03	0,14-0,23 (0,19)	0,001**
	PET	10	0,19±0,09	0,01-0,31 (0,2)	
	PLA	10	0,29±0,25	0,15-0,97 (0,2)	
	Resin	10	0,27±0,16	0,17-0,6 (0,2)	
5 cm	ABS	10	0,49±0,27	0,11-0,91 (0,44)	
	PET	10	0,44±0,29	0,04-1,06 (0,37)	
	PLA	10	0,52±0,39	0,1-1,5 (0,46)	
	Resin	10	0,5±0,72	0,11-2,49 (0,24)	
10 cm	ABS	10	0,56±0,6	0,02-1,89 (0,39)	
	PET	10	0,05±0,03	0,01-0,11 (0,05)	
	PLA	10	0,07±0,12	0,02-0,41 (0,04)	
	Resin	10	0,11±0,19	0-0,58 (0,03)	

Kruskall Wallis Test *p<0,05 **p<0,01

Table 4.4. Comparison of apex linear values according to the material of the groups

APEX		n	Mean±Sd	Min-Max (Median)	p
ABS	**2 cm**	10	0,18±0,03	0,14-0,23 (0,19)	0,079
	5 cm	10	0,49±0,27	0,11-0,91 (0,44)	
	10 cm	10	0,56±0,6	0,02-1,89 (0,39)	
PET	**2 cm**	10	0,19±0,09	0,01-0,31 (0,2)	0,001**
	5 cm	10	0,44±0,29	0,04-1,06 (0,37)	
	10 cm	10	0,05±0,03	0,01-0,11 (0,05)	
PLA	**2 cm**	10	0,29±0,25	0,15-0,97 (0,2)	0,001**
	5 cm	10	0,52±0,39	0,1-1,5 (0,46)	
	10 cm	10	0,07±0,12	0,02-0,41 (0,04)	
Resin	**2 cm**	10	0,27±0,16	0,17-0,6 (0,2)	0,001**
	5 cm	10	0,5±0,72	0,11-2,49 (0,24)	
	10 cm	10	0,11±0,19	0-0,58 (0,03)	

Kruskall Wallis Test *p<0,05 **p<0,01

2 cm group has no statistically significant difference than each other inside of the group.

ABS-2 has statistically significant lower deviations than ABS-5, PET-5, and PET-5. It has lower deviation than Resin-5 but it is not statistically significant. ABS-2 has statistically significant higher deviations than PET-10, PLA-10, and Resin-10. It has lower deviation than ABS-10 but is not statistically significant.

PET-2 has statistically significant lower deviations than ABS-5, PET-5, and PET-5. It has lower deviation than Resin-5 but it is not statistically significant. PET-2 has statistically significant higher deviations than PET-10 and PLA-10. It has higher deviation than Resin-10 and lower deviation than ABS-10 but they are not statistically significant.

PLA-2 has statistically significant lower deviation than ABS-5. PLA-2 has lower deviations than other 5 cm groups, but it is not statistically significant. PLA-2 has statistically significant higher deviations than PET-10, PLA-10, and Resin-10. It has lower deviation than ABS-10 but it is not statistically significant.

Resin-2 has statistically significant higher deviations than PET-10, PLA-10, and Resin-10. It has lower deviations than all other groups, but they are not statistically significant.

5 cm group has no statistically significant difference than each other inside of the group.

All the ABS-5, PET-5, PLA-5, and Resin-5 has statistically significant higher deviations than PET-10, PLA-10, and Resin-10. Again, all of them has a lower deviation than ABS-10 but they are not statistically significant.

ABS-10 has statistically significant higher deviations than PET-10, PLA-10, and Resin-10.

This result shows us 10 cm has better accuracy at the apex of the implant. 2 cm has better results than 5 cm ones and unlike top scores some 2 cm apex deviations statistically significantly lower than 5 cm ones.

As in the top measurements, PET has the lowest deviations. ABS has highest deviations overall, but it is not statistically significant other than the 10 cm group.

4.3. Angular Body Deviation of the Pin

Angular deviation value shows statistically significant difference between groups.

Table 4.5. Comparison of angular values according to the dimensions of the groups

ANGLE		n	Mean±Sd	Min-Max (Median)	p
2 cm	ABS	10	0,29±0,17	0,02-0,52 (0,32)	0,001**
	PET	10	0,33±0,2	0,07-0,65 (0,27)	
	PLA	10	0,65±1,02	0,08-3,51 (0,29)	
	Resin	10	0,52±0,51	0,18-1,67 (0,29)	
5 cm	ABS	10	0,94±0,83	0,01-2,21 (0,66)	
	PET	10	1,32±1,11	0,25-4,04 (1,09)	
	PLA	10	1,27±0,76	0,06-2,19 (1,33)	
	Resin	10	1,22±1,43	0,19-4,99 (0,67)	
10 cm	ABS	10	1,72±1,9	0,05-5,84 (1,11)	
	PET	10	0,18±0,14	0,01-0,48 (0,15)	
	PLA	10	0,28±0,41	0,03-1,43 (0,15)	
	Resin	10	0,41±0,74	0,04-2,2 (0,06)	

Kruskall Wallis Test *p<0,05 **p<0,01

Table 4.6. Comparison of angular values according to the material of the groups

ANGLE		n	Mean±Sd	Min-Max (Median)	p
ABS	2 cm	10	0,29±0,17	0,02-0,52 (0,32)	0,103
	5 cm	10	0,94±0,83	0,01-2,21 (0,66)	
	10 cm	10	1,72±1,9	0,05-5,84 (1,11)	
PET	2 cm	10	0,33±0,2	0,07-0,65 (0,27)	0,001**
	5 cm	10	1,32±1,11	0,25-4,04 (1,09)	
	10 cm	10	0,18±0,14	0,01-0,48 (0,15)	
PLA	2 cm	10	0,65±1,02	0,08-3,51 (0,29)	0,022*
	5 cm	10	1,27±0,76	0,06-2,19 (1,33)	
	10 cm	10	0,28±0,41	0,03-1,43 (0,15)	
Resin	2 cm	10	0,52±0,51	0,18-1,67 (0,29)	0,007*
	5 cm	10	1,22±1,43	0,19-4,99 (0,67)	
	10 cm	10	0,41±0,74	0,04-2,2 (0,06)	

Kruskall Wallis Test *p<0,05 **p<0,01

2 cm group has no statistically significant difference than each other inside of the group.

ABS-2 has statistically significant lower angulation than all the 5 cm groups.

PET-2 has statistically significant lower angulation than PET-5, PLA-5, and Resin-5. It has lower angulation than ABS-5 as well but it is not statistically significant. PET-2 has statistically significant higher angulation than Resin-10. PET-2 has higher angulations than PET-10 and PLA-10 and lower angulation than ABS-10 but they are not statistically significant.

PLA-2 and Resin-2 have statistically significant lower angulation than PET-5. They have lower angulations than ABS-5, PLA-5, and Resin-5 but values are not statistically significant. PLA-2 has statistically significant higher than PET-10, PLA-10, and Resin-10. It has a lower angulation than ABS-10 but it is not statistically significant.

Resin-2 has statistically significant lower angulation than PET-5. It has lower angulations than ABS-5, PLA-5, and Resin-5 but they are not statistically significant. Resin-2 has statistically significant higher angulations than PET-10, PLA-10, and Resin-10. It has lower angulations than ABS-10 but it is not statistically significant.

5 cm group has no statistically significant difference than each other inside of the group.

ABS-5 has statistically significant higher angulations than PET-10 and PLA-10. It has higher angulation than Resin-10 and lower angulation than ABS-10 but they are not statistically significant.

PET-5, PLA-5 and Resin-5 are all have statistically significant higher angulations than PET-10, PLA-10, and Resin-10. They all have lower angulations than ABS-10 but they are not statistically significant.

ABS-10 has higher angulations than all the 10 cm groups but the only statistically significant one is between Resin-10 one.

In angle test, 5 cm has the worst results. 10 cm groups have lower angulation values than 2 cm ones. PET has better results in 2 cm and 10 cm groups, but ABS and Resin are better in 5 cm group.

According to the tests there were variable results. Four types of materials in three different dimensions were assessed. Two different points were measured – apex and top of the pin – and the angle of the pin.

5. DISCUSSION

Dental implants are miraculously solving the missing teeth problems for many years. Brånemark found osseointegration without purpose on a rabbit leg in 1952 and opened an era with the commercial use of cylindrical implants in 1981. During this three decades he made many studies even on his assistant colagues (37–39). His work was not only about dental implants but also osseointegration (40). At Toronto osseointegration conference in 1982 machined titanium implants were introduced to many dental communities and became spread world-wide (41,42).

Manufacturing technologies and material variety has dramatically increased after industrial revolution. Products started to be produced in shorter times with less energy. Raw materials are getting cheaper, and this makes them accessible by large amount of people. World become global and getting smaller since 80s. People all around the world can communicate each other. This information eases technology to develop in a logarithmic manner. Eastern countries such as China and Taiwan make new electric and electronic devices accessible to worldwide in a reasonable price. Additive manufacturing is not a recent concept. It started its life mainly as a prototyping concept and was used by few industrial companies.

In recent years, research about biodegradable materials in plastic consuming products has increased (43). Waste accumulation is getting a bigger problem as population and consumption grows. PLA has an advantage in this situation over PET and ABS (44,45).

Biodegradable polymer has also advantages inside of the human body. Biodegradable materials eliminate the necessity of the removal of the implant that is placed. This increases patient comfort and operation success and reduces the potential infection. Non-biodegradable materials do not have this advantage. It is not only limited with an implant there are a variety of applications possible. Degradable sutures, cellular applications with porous scaffolds and drug releasing micro and nano particles are some examples that PLA types can do (46,47).

Pressure, impact, shear, tensile are some of the loading modes that describes the behaviors of mechanical properties of a material. PLA has advantage in terms of Young's modulus over PET (48). Elongation at a break and impact strength values are better in

PET rather than PLA (49). At higher stress levels PLA can show a plastic deformation characteristics (50).

PLA is an amorphous, semi-crystalline polymer with the glass transition temperature of 55 °C and melting temperature of 180°C (51). PLA can be used in packaging applications of daily consumption products. This is possible because of it has barrier properties of CO_2, O_2, N_2 and H_2O. Permeability of these factors are lower than some biopolymers but higher than PET. This means it is required more development in permeability properties (52).

Resolving of a material into carbon dioxide or methane and water is the most common definition of biodegradation. According to the Japanese Biodegradable Polymer Society (JBPS), when a polymer is divided into water and carbon dioxide with the help of microorganisms in the nature, it is called Green Plastic. Complete biodegradation is a term when substrate totally mineralizes and there will be no residue just gaseous products. Temperature and humidity of the medium affects the rate of biodegradation (51). PLA also studied in human and animal bodies. Degradation helps in application such as sutures, drug delivery methods and implants. PLA undergoes hydrolysis reaction in the body and oligomers appeared after are metabolized by living cells (53,54).

Tissue engineering term was first suggested in 1987 (55). It aims to correct an organ failure or replace tissue loss and it is a multidisciplinary field including engineering, chemistry, physics and biology (56). PLA and its derivative co-polymers have aliphatic polyester characteristics, and they are popular in tissue engineering. It is biocompatible. It can dissolve in the body so it can be a significant alternative to traditional metallic or ceramic materials (57). Dissolving action takes place by hydrolysis of ester backbone to harmless and non-toxic compounds.

PLA has poor mechanical properties so it is more suitable for applications that does not need to expose to impact like bone scaffolds (58). PLA and co-polymers like PLA-polyethylene glycol block copolymer (PLA-PEG) and PLA-p-dioxanone-polyethylene glycol block copolymer (PLA-p-DPEG) were used to transfer bone morphogenetic proteins (BMPs). BMPs has the ability of inducing new bone formation. They are active molecular and PLA is found to be a good candidate as carrier (59). Low molecular weight PLA can be mixed with BMP to gain a composite material. When this composite is applied to host bone, new bone cells are appeared but newly-formed bone has a lower volume comparing to the initial size (60). Another study working with a porous PLA composite scaffold and recombinant bone morphogenetic protein 2 (rhBMP2) shows scaffolds exhibits a sufficient capacity of transferring rhBMP2. In this study new bone formation was seen in two weeks (61).

Maia-Pinto et al. have combined PLA with calcium phosphate. They have made scaffolds with PLA-CaP and biomimetically coat them with apetite on human primary osteoblast. The study was made on rats. 8mm critical defects were created and prepared scaffolds were placed. Control group was only rhBMP-2 and test group were combination of PLA-CaP with rhBMP2. Test group showed 44.85% more new bone formation after 6 months (62).

Kao et al. combined PLA with polydopamine (PDA). PDA consist of indole and dopamine. It is used as a surface material and increases adhesion on surface. In this study PLA scaffolds were coated with mussel-inspired PDA. Authors have used human adipose-derived stem cells (hADSCs). Cell adhesion, proliferation and differentiation were tested. As a result, adhesion was significantly higher on PDA/PLA combination rather than pure PLA subjects. In addition, collagen I secreted from cells, and this promoted cell attachment and cell progression. ALP activity, ang-1 and vWF proteins associated with angiogenic differentiation is relatively high in PDA/PLA combination. This study shows PDA is a promising tool to carry and regulate stem cell activity and important in bone tissue engineering as well (63). Amnael Orozco-Diaz et al. have made a similar study (64) with hydroxyapatite composite of PLA. It is found that 10% hydroxyapatite mixture with PLA increases cell attachment, calcium deposition and collagen deposition on tissue.

Membranes are key factors in guided bone regeneration. Today PLA and PLA derivative membranes are produced by solvent cast method. Zhang et al. have compared traditional solvent cast membranes with the 3D printed PLA membranes. They have made 3 different pore sizes (large pore-479 µm, small pore-273 µm and no pore. They have tested mechanical properties and cell proliferation. As the pore size increases, mechanical properties such as tensile strength, elastic modulus, and elongation at break decrease. Preosteoblast cells were cultured on membranes. Results were similar to the mechanical properties. As pore size increases cell medium properties decreases. No pore 3D printed membrane have showed superior mechanical and biological properties to those of solvent membranes (65). It is possible to produce personalized patient-based membranes with 3D printing.

Pentek et al. have compared mechanical properties of ABS and PLA as well as electric conductivity for manufacturing upper limb prosthesis. They have stated that limb loss is quite common worldwide (66). For this purpose FDM printers can be uses for the production of limb prosthesis (67,68). They have found that PLA, has given closer characteristics in electric conductivity to ABS but overall ABS had more advantages in electrical and mechanical properties than PLA (69).

Investment casting is a process for creating complex shape products with mold. Additive manufacturing is taking place in this area. Investment casting also takes place in dentistry. Crown and partial prosthesis substructures use metal basis, and they are produced with this method for many years. A study has worked on FDM printers with PLA and ABS. They searched for dimension comparison and surface roughness. In this study ABS has given better scores just after print, but PLA is advantageous in casting process. They found that PLA is more suitable for investment casting process (70).

FDM printer filaments are thermoplastic materials. To give them desired shape heat is applied during printing process. When heat is applied some ultrafine particles and volatile organic compounds are emitted (71–74). This study shows that ABS has high and PLA has low emittions (75). It is generally suggested to ventilate the room. Ventilation should be calculated correctly otherwise it increases the volatile organic compounds inside of the room. If the printer is in closed case a filter can be place to the air outlet otherwise operator can wear a mask during printing process.

Recent articles are no longer mention about whether to use the additive manufacturing in medical field. It is popular to increase the tensile strength or to find custom solutions for the situations that is already be solved with mass production devices (76). Surgical instruments were mass produced and catalogued before but with the additive manufacturing “The Second Industrial Revolution” (77) is now possible to create devices for the surgeons needs (78,79).

Custom impression trays have a lot of benefits than stock trays. The impression material shrinks more when it is thicker. It is more difficult to take detailed impressions with stock tray because forces do not apply evenly. It is important the impression material to bond to the tray. Y. Xu et al. have conducted a study in dentistry field. They have compared custom trays with different manufacturing techniques and different materials. Y. Xu et al evaluated 3 Additive Manufacturing technologies (SLA, DLP and FFF) with 3 elastomeric impression systems (vinylsiloxantether (VSXE), VPS, and polyether (PE)) using peel test. They have compared these materials with a light curing resin that is accepted as gold standard in custom tray fabrication. All the printed trays have given adequate results for clinic usage. Different printing techniques creates different surface topographies and different results. SLA and DLP printers gave smoother surfaces. Due to its nature FFF printing and PLA gave rougher surface comparing to the other 2 methods and show better performance in terms of bonding impression material to tray. To sum up all 3D printed trays work fine in clinic use (80).

Molinero et al. have carried a study about making provisional and temporary PLA restorations. It was about marginal fit. According to the author the study was the first that analyzed temporary crowns made by FDM technology, so it was not possible to compare the results with the previous studies. Instead, Molinero et al. have compared PLA with PEMA, PMMA and bis-acrylic composites. They have stated that, PLA has given similar results to PMMA restorations and it was in acceptable limits (81).

Layer thickness is a parameter that can be changed by user. Layer thickness is able to affect some physical properties of 3D printed specimens (82). Farzadi et al. have reported printing orientation and layer thickness affects compressive strength and dimensional accuracy of 3D printed materials (83). It was found that 0.1125 mm layer thickness and longitudinal x direction were the best printing conditions. Wu et al. have discovered that polyether-ether-ketone (PEEK) impact strength, tensile strength and flexural strength are influenced by printing layer thickness (84). The optimal mechanical properties were found at a layer thickness of 300 µm. Liu et al. have observed different layer thicknesses in terms of tensile bond strength, flexural strength, tensile strength, printing accuracy, and printing time of custom designed trays in a simulated clinic situation. A desktop-class FDM printer and PLA was used in the study. 0.1-, 0.2-, 0.3-, 0.4- and 0.5-layer heights were tested. As the thickness increased tensile bond strength first increased, peaked at 0.4 mm and then decreased. Tensile and flexural strengths decreased. Printing accuracy decreased at 0.5 but remained same in the others. Obviously printing time decreased as layer height increased. As a result, moderate thicknesses such as 0.3 and 0.4 were found the best for 3D custom trays (85).

Bracket positioning is essential in orthodontics. It can be directly done in patients mouth or can be done on a plaster model and then transferred to patients mouth. Both method have advantages and disadvantages compared to each other (86). Kulkarni et al. have studied on indirect orthodontic bracket transfer trays with two different materials. The study was about comparison of in-house production methods. Hot glue applied with glue gun and PLA applied with 3D filament pen. A 3D printing pen worked like a hot glue gun. It produces heat at the tip of the pen like a nozzle in 3D printer, and melt filament was pushed from the tip of the pen. Impression materials, vacuum-formed thermoplastic materials, light-cured transparent resins were discussed by previous authors, but hot glue and PLA were first compared by Kulkarni et al. They have observed failure rates by materials, by arches and by tooth positions in arches. Hot glue is a soft and flexible and PLA is a rigid material after their final shape. PLA have provided more precise positioning than hot glue, but the author was faced more bracket debonding while removing the PLA tray from mouth. In contrast hot glue have made it easier to remove the tray from the mouth after bonding brackets but since it is a flexible material positioning of the bracket were less accurate than PLA. Overall hot glue had better result in terms of both initial and long term debonding of the brackets but it is concluded as both in-house systems were acceptable for clinic use (87).

Zhang et al. have made a similar comparison in bracket positioning between SLS 3D printers and double layered thermoforming guide plates. Double layered plates are softer inside and harder outside. When the inner softer layer gets thinner it become more precise. SLS printers and traditional thermoforming plates had no significant difference according to that study. Traditional method requires less time and less work. This means it is more practical in chairside but 3D planning and designing a model gives more opportunities in clinic use (88).

In dentistry locator guides not only used for implant location but they can also locate an impacted tooth location. Adersh et al. have made a study to locate and extract an impacted tooth. The patient had a missing upper premolar and in CT views it was seen as impacted mostly on the palatal side. An osteotomy was needed to extract that tooth and to make the osteotomy minimal Adersh et al. have made a PLA guide and extracted the tooth successfully and minimal invasively. The reason why they have chosen PLA instead of resin is to develop more bio-friendly guide (89).

In denture fabrication different methods can be used. There are several steps to test the denture, before producing the final product. Wax is generally used as a base try. Wax can be put on a stone cast manually or can be done by wax 3D printer. Deng et al. have made a pilot study and have fabricated this base from PLA instead of wax. They have tested the contact distance between test specimen and stone cast. PLA has given similar results with wax and process was not more difficult than wax (90).

The aim of this study to compare ABS, PET, and PLA with Resin in the production of dental implant surgical guide production.

The study was carried on 3 different sizes. Different sizes represented different edentulous sizes of jaws. 2 cm was single tooth missing, 5 cm bridge a 10 cm was total edentulous jaw or a guide that cover whole arch.

Test measurements were done in 3 sections.

If the implant is not correctly placed inside of the mouth it effects the crown procedure. First measurement was linear deviation at the top of the pin. The top of the pin represented the top of the implant in real life. Proximity to adjacent tooth is an important factor. There should be sufficient space for abutment and crown itself.

In 2 cm blocks there were no statistically significant difference in material groups.

In 5 cm groups ABS showed statistically significant higher values than PET and Resin group in terms of top linear deviations.

In 10 cm blocks there were no statistically significant difference in material groups.

PET-5 and PLA-5 groups shows statistically significant higher values than PET-10, PLA-10, and Resin-10.

In the production of single tooth or total arch guide, material choice does not change the position of the implant at the top. In a bridge restoration guide ABS should not be the material of choice. 5 cm groups showed lower performance than 10 cm groups and according to this result a full arch guide should be chosen for a bridge restoration.

Implant body and tip can be close to adjacent tooth or anatomical structures. The second measurement was the linear deviation of the apex of the pin. If the implant is misplaced, it can damage these close structures or the surrounding bone around the implant can be less than healthy margins.

In 2 cm blocks there were no statistically significant difference in material groups.

In 5 cm blocks there were no statistically significant difference in material groups.

In 10 cm groups ABS showed statistically significant higher values than PET, PLA, and Resin group.

PET, PLA, and Resin had best scores in 10 cm group and worst scores in 5 cm group.

In the production of single tooth or total arch guide, material choice does not change the position of the implant at the apex. In full arch restoration ABS should be avoided. As in the top measurement test 10 cm groups showed higher performance than 5 cm groups and this showed us full arch guide should be chosen for a bridge restoration.

Occlusal forces on an implant should be perpendicular or similar to maintain the structural integrity of abutment and implant body. The third measurement was the angular deviation of the implant body. If the angulation is more than limits, damage can be seen on abutment, implant, and crown, fixture failures can be observed between implant, abutment and crown or resorption can be seen around the surrounding bone of the implant.

In 2 cm blocks there were no statistically significant difference in material groups.

In 5 cm blocks there were no statistically significant difference in material groups.

In 10 cm groups ABS showed statistically significant higher results than Resin group.

PET, PLA, and Resin had best scores in 10 cm group and worst scores in 5 cm group in terms of apex measurement test.

In the production of single tooth or total arch guide, material choice does not change the angulation of the implant body. In full arch restoration ABS should be avoided. As in the top and apex measurement test 10 cm groups showed higher performance than 5 cm groups and this showed us full arch guide should be chosen for a bridge restoration.

3D printed parts have dimensional distortions and this increases as the part gets bigger and become less visible when the part gets smaller. In this study it was expected that 10 cm guides would show the most deviations, but 10 cm guides gave the best results in top linear deviation, apex linear deviation and angular deviation. PET, PLA, and Resin gave consistent result. They all gave the best results in 10 cm blocks than in 2 cm blocks and 5 cm blocks. These results show us full arch guides gave best accuracy. Single tooth guides still give reasonably good results. In the case of partial edentulous jaws, a full arch guide should be chosen according to these results.

For the material choice PET gave the best results. PLA and Resin are good and still usable materials according to this test. ABS – because of its nature – had the lowest scores. ABS is very sensitive to heat changes and prone to warp. This result was expected before the testing. According to these results, PET and PLA can be used as guide material but ABS is not suitable for guide production.

6. CONCLUSION

This study was planned to investigate the precision of the materials of ABS, PET, and PLA and FDM printing technology and compare them with Resin printing technology. In order to compare them a simple geometric test blocks were prepared, and implant-like pins were put into the blocks. Pin sockets were prepared with the guides that are made of our study materials. In order to see the difference of the pins, CT images of every block was taken. DICOM images were acquired and then converted into STL data. Linear and angular deviations were calculated according to this STL data.

- Resin printer's layer thickness is 50 µm while FDM printer's layer thickness is 200 µm. In this study this four times resolution advantage of resin printer did not make better results than FDM printer and PET filament.

- PLA is resorbable in the nature and ABS and PET are recyclable. Resin does not have ecological characteristic. This makes filament materials not only have reasonable price but also sustainable.

- 2 cm guides take approximately 30-40 minutes to print while larger 10 cm one takes about 90-100 minutes. Resin printer prints the same height approximately in 50-60 minutes. In resin printers width and depth does not change the print time. The only variable parameter is height but in FDM printers all of them changes total print time.

- PET is food safe which means it does not cause a reaction in oral mucosa, but it does not claim biocompatibility. Resins does not claim it either. There are some manufacturers that have some "non-toxic" resins, but this does not completely mean that they are biocompatible. There are ongoing studies on this product. In fact, surgical guides do not need to be biocompatible. So, it is not a drawback for PET or Resin.

- According to the results PET gives the lowest deviations. PLA and Resin have related results. ABS has the highest deviations and most of them are statistically significant, so this makes it unusable for this purpose. For guide production PET and PLA are usable alternatively to Resin in this study. Further studies on more complex shapes allows us to see the limits of these materials. PLA is a very promising material in regeneration concept. Ability to form it in a desired shape can change the limits of bioregeneration concept.

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8. BIOGRAPHY

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