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Three-Dimensional scanning in Orthodontics

A project submitted to

The College of Dentistry, University Of Baghdad, Department of Orthodontic, in partial Fulfilment for the Bachelor of Dental Surgery

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Certification of the Supervisor

I certify that this project entitled" **Three-Dimensional scanning in Orthodontics**" was prepared by the fifth-year student **Safa Abdulfattah Khairy** under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Supervisor's name: **Dr. Dhilal Al-Rudainy**

Date:

Dedication

To my parents, my mother who gave me her life and always supported me,
To my father who I am sure is very proud of me now, I wont be here without you.
To my lovely brothers and sisters who were always beside me.
To my friends who I spent this lovely journey with them.
Thank you all for being supportive.

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IOS	Intra oral scanner
PVS	Poly Vinyl Siloxane

Introduction

Two-dimensional (2D) imaging technology, such as cephalometric and panoramic radiographs and photographs, and plaster models were used routinely in dentistry and in orthodontic specifically **(Erten & Yılmaz, 2018).**

However, there are some limitations of 2D imaging systems as significant amount of radiographic projection error, enlargement, distortion, exposure to radiation, weaknesses of landmark identification, inaccurate duplication of measurements, significant variation in the position of reference points, such as sella turcica, and extreme limitations in assessing soft tissue **(Jacobson A, 1995)**.

It is crucial to maintain precise records of treatment progress since a poor record might suggest a low degree of orthodontic therapy (Peluso et al., 2004) After the introduction of 3D imaging systems, it was possible to evaluate structures in real three anatomical dimensions **(Erten & Yılmaz, 2018b).**

Today, using 3 dimensional (3D) digital technologies, 3D models are considered as a revolutionary advancement in the orthodontic practice **(Akdeniz et al., 2022)**. More recently, facial scanners have found a foothold in the digital dental workflow (J. D. Lee et al., 2022) Beside the simplicity of storing and transferring, 3D models also opened doors for new diagnosis and treatment options such as 3D planning of orthognathic surgery and clear aligner therapy, which are considered as the future of orthodontic mechanics **(Akdeniz et al., 2022)**.

Digital impressions have brought innovation to impression taking, and have partially side lined the conventional methods (alginate and PVS (Polyvinyl Siloxane) (G. J. Christensen, 2008).

However, it still had limitations that might affect the practical work **(Ender & Mehl, 2013; Güth et al., 2016).**

Aim of the Study

This study aimed to explore 3D laser scanning in orthodontics. The objectives of this study were to demonstrate

- Types of laser scanning in orthodontics.
- Basic principles.
- Clinical applications.
- Advantages and limitations of 3D laser scanning.

1 Chapter one: Review of literature:

1.1 Intraoral scanning

Intra Oral Scanner(IOS) is a medical device used for capturing direct optical impressions, composed of a handheld camera (hardware), a computer and a software**(Richert et al., 2017)** The goal of an IOS is to record with precision the three-dimensional (3D) geometry of an object by projecting a light source onto the object to be scanned **(Seo et al., 2017)**

1.1.1 Components of IOS

The Intraoral scanners have 3 major components **(Kravitz et al., 2014) (Figure 1.1)**:

- Wireless mobile workstation that support data entry.
- A computer monitor to enter data, approve scans and review digital files.
- Handheld camera to collect the scanned data in the patient mouth.

Figure 1.1: Components of IOS(Aljabaa, 2021)

Together surface data points, energy from either laser light or white light is projected from the wand onto an object and reflected back to a sensor or camera within the wand **(Kravitz et al., 2014)**.

1.1.2 Types of intraoral scanners

1.1.2.1 The 3M True definition scanner:

Accoding to **(Aljabaa, 2021)** the 3M scanner was firstly produced in 2008 using an active wavefront sampling technology and the resulting classic scanner provided good performance at that time. later this scanner had improved its specifications by the company and produced The True definition scanner which has the same software/hardware as the original one**(Figure 1.2)**.

Figure 1.2: The 3M True definition scanner (Aljabaa, 2021)

The device is characterized by provides High accuracy. It scan single units ,multiple unit, long span bridges or full arch. The tip has the same size of the hand piece. Requires thin layer of powder to have high accuracy. It doesn’t offer real time full colour scan. It has open software.

1.1.2.2 CEREC Omnicam by Sirona Dentsply:

According to **Aljabaa(2021)** it has strong name in restorative dentistry, it applies the triangulation imaging technology. It provides video streaming instead of static image where powdering is not required and possibility of full arch scan**(Figure 1.3)**.

Figure 1.3: CEREC omnicam by sirona Dentsply (Aljabaa, 2021)

1.1.2.3 The planmeca Emerald (PE):

According to **(Aljabaa, 2021)** it is consist of scanning tip ,cable ,cradle and color balancer, it was launched in 2017. Class 2 laser scanning device with 400-700 nm. It utilises optical triangulation and software algorithm to construct 3D object, contact free , powder free IOS system**(Figure 1.4)**.

Figure 1.4: The planmeca Emerald (Aljabaa, 2021)

1.1.2.4 The 3 Shape Trios (TR):

According to **(Aljabaa, 2021)** it is launched the first edition of TRIOS 3 in 2010. In the beginning there were a lot of complain in the wand but later the company solved it. By using this scanner, The operator can perform the scanning as soon as it is turned on. The scanner wand is downsized and the wand sleeve can be sterilised by autoclave.

The scanning technology is ultrafast optical sectioning(confocal laser principle). In 2017, the wireless version was launched offer the flexibility and freedom in use to the operator**(Figure 1.5)**.

Figure 1.5: The 3 Shape Trios (Aljabaa, 2021)

1.1.3 Applications of IOS in Orthodontics

In orthodontic, IOS can help in:

1. Digital Indirect bonding **(Herrall, 2018)(Figure 1.6)**: Digital version of indirect bonding eliminated the need for complex laboratory and clinical processes. There are currently three different ways for digital indirect bonding **(Akdeniz et al., 2022).** The most basic way is 3D printing the study models and applying conventional indirect bonding steps which were normally applied on plaster models **(Akdeniz et al., 2022)**.

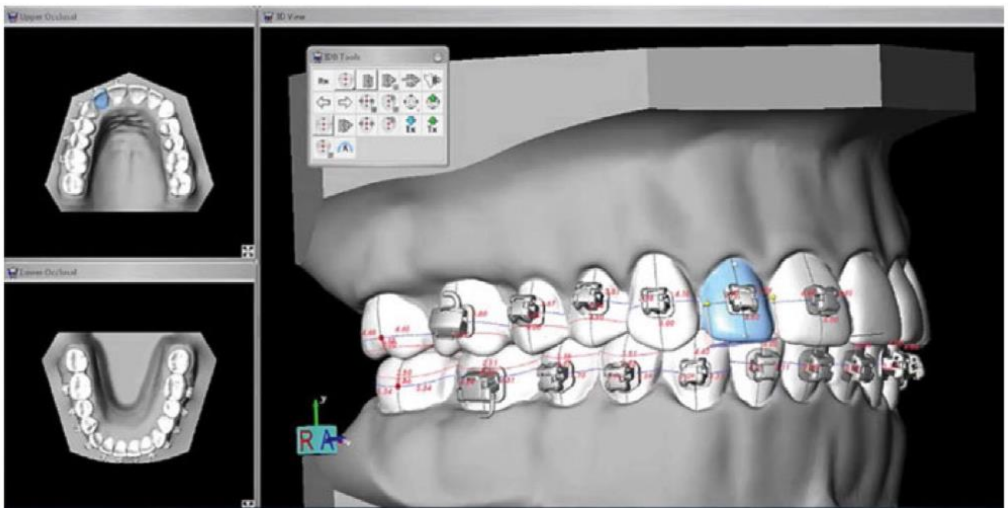


Figure 1.6: Digital indirect bonding (www.orthopracticeus.com)

Akdeniz et al(2022) reported second method includes using of software individually designed for indirect bonding. Brackets are virtually placed on digital models in the software. Some of the programs can apply basic set-up on the dental models to show a forecast of possible treatment options. User can choose from the 3D data of the brackets which are stored in the software's own library. Digital study models with placed brackets can be 3D printed to fabricate the transfer trays from silicone or thermoform materials in the laboratory. Real brackets are then placed in the grooves on the transfer tray**(Figure 1.7)**.

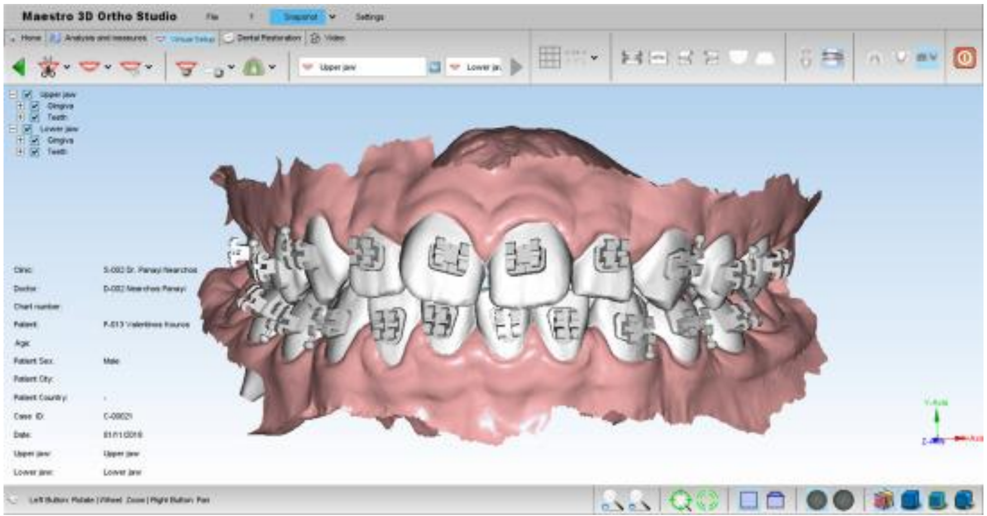
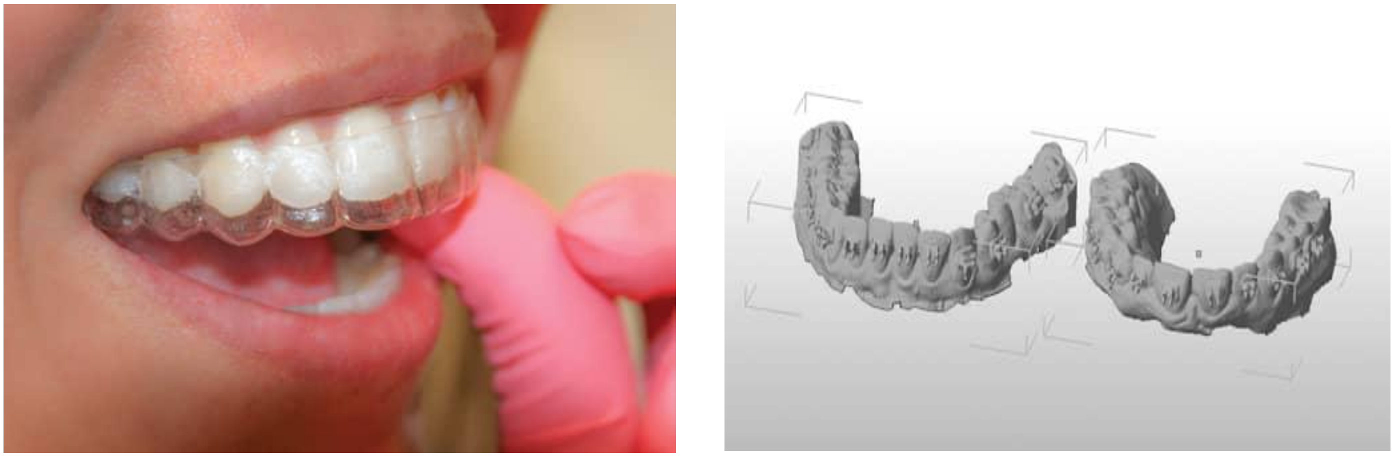


Figure 1.7: Software individual design for indirect bonding (Nearchos C.Panayi et al., 2020).

According to **(L. R. Christensen & Cope, 2018)** In the third way the users can finish all the above workflow digitally including the design of the transfer trays. The trays are 3D printed with a flexible resin and brackets are placed in their grooves. Although digital indirect bonding technology is promising in decreasing chair time and laboratory steps, there are some concerns about high error rate of the system **(Ciuffolo et al., 2006)**.

2. Digitally fabricate orthodontic appliances **(Harrel, 2018)**: High precision 3D printing technology is being used to produce variable orthodontic appliances like retainers, removable appliances and occlusal splints **(Hazeveld et al., 2014)(Figure 1.8)**.



A B

Figure 1.8: A) Retainer made with digital impression, B) Upper and lower digital impressions (www.orthodonticproductsonline.com).

3. Facilitate orthodontic diagnosis and treatment planning, offering easy and fast electronic transfer of data, immediate access, and reduced storage space requirements **(Rheude et al., 2005).**
4. They provide the orthodontist with numerous applications, such as measurements of arch width and length, tooth size, transverse dimensions, Bolton discrepancy, overjet, and overbite, which are obtained with a remarkable accuracy and efficiency **(Harrel, 2018)**.
5. Create a digital diagnostic set-up, and simulate a proposed treatment plan **(Fleming et al., 2011).**
6. Clear aligner technology: Today, one of the most important use of 3D printing technology is the production of clear aligners **(Akdeniz et al., 2022).**
7. Orthognathic surgery simulation and wafer construction **(Cousley & Turner, 2014; Gateno et al., 2007):** This made it possible to eliminate most of the time-consuming conventional model surgery steps including the face bow transfer **(Akdeniz et al., 2022). (Cousley & Turner, 2014)** confirmed that digital

surgical planning and wafer production techniques achieved level of accuracy, that match the conventional face bow and model surgery. **(De Riu et al., 2014)** reported that digital planning was even more successful than conventional planning for the orthognathic correction of facial asymmetry**(Figure 1.9)**.

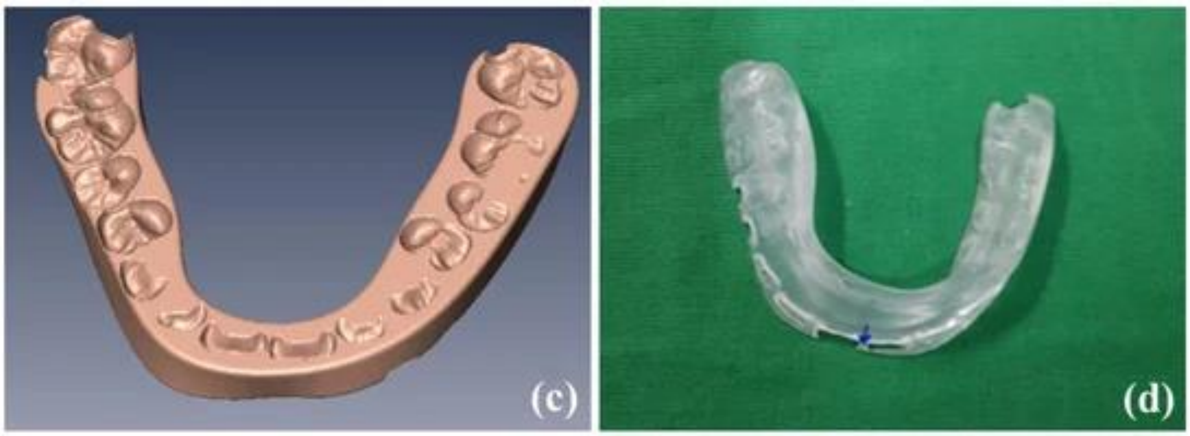


Figure 1.9: Digital surgical splint model (left) and a physical splint fabricated via 3D printing (right) (Lee et al., 2021).

1.1.4 Advantages of IOS

There are many advantages of Intra oral scanners over the traditional impressions which include:

1. Time efficiency: Several studies have shown that optical impressions are time-efficient, as they enable reduction of the working times when compared to conventional impressions **(Burhardt et al., 2016; Goracci et al., 2016; Yuzbasioglu et al., 2014).**
2. Less patient discomfort: The ability to directly capture all dental arch information of the patient, and consequently their 3D models, without using

conventional physical impression **(Ahlholm et al., 2018; Chochlidakis et al., 2016; Ting-shu & Jian, 2015).**

3. Better communication with the dental technician: With IOS, the clinician and the dental technician can assess the quality of the impression in real-time **(Joda & Brägger, 2015; Lee & Gallucci, 2013; Patzelt et al., 2014).**
4. Simplified procedures for the clinician: simplifying impression-making in complex cases, for example in the presence of multiple implants or severe undercuts **(Goracci et al., 2016a; Zimmermann et al., 2015a).**

1.1.5 Basic principles of IOS

1.1.5.1 Triangulation

In this technology, angles and distances are measured from known points with projected laser light. Firstly, the distance and angle between the sensor and laser source are known.When light projected from the source and reflected of the object, then the system determines the angle of reflection and therefore the distance from the laser source to the object’s surface according to Pythagorean theorem. It is required a thin coating of opaque powder to be applied to the target tissue and an example of this is CEREC system **(Kravitz et al., 2014; Taneva et al., 2015)(Figure 1.10).**

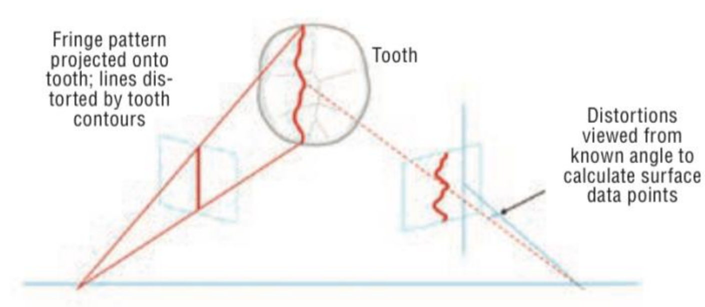


Figure 1.10: Triangulation technology (Groth et al., 2014)

1.1.5.2 Parallel confocal

In this technology, the sensor will placed at confocal (in focus) imaging plane relative to the target in which a small aperture located in the front of the sensor blocks any light from above or below the plane of focus so, only the focused light will reflecting of the target and re enter the filter and reach the sensor for processing. The accuracy of the scan will optimising because the out of focus light(bad data) is eliminated. This technology is depends on a process called "point-and-stitch reconstruction" in which parallel confocal system tomographically slices the object and then stitch together thousands of slices of data to create a complete picture **(Groth et al., 2014; Taneva et al., 2015)(Figure 1.11)**.

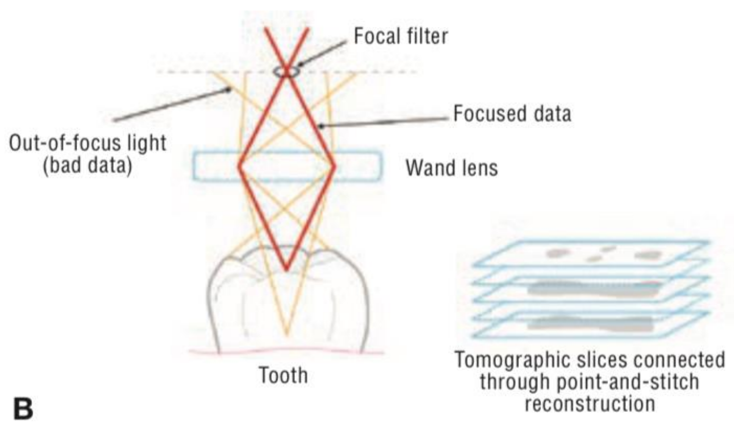


Figure 1.11: Parallel confocal technology (Kravitz et al., 2014).

1.1.5.3 Accordion Fringe Interferometry (AFI)

In this technology, we use two sources of light to project three patterns of light that called "fringe patterns". When the fringe pattern hit the object(teeth and tissue), it distorts and takes a new pattern according to the unique curvature of the object and this distortion is called “fringe curvature”. A high definition (HD) video camera that is offset from the projector by about 30 degree will then record the surface data points of the fringe curvature **(Kravitz et al., 2014; Logozzo, Zanetti, et al., 2014)(Figure 1.12)**.

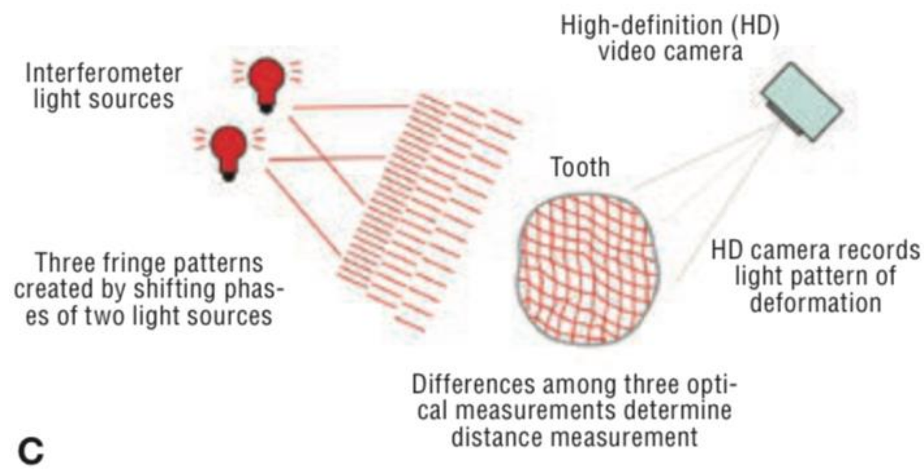


Figure 1.12: Accordion Fringe interferometry technology (Kravitz et al., 2014)

1.1.5.4 Three dimensional in motion video

In this technology, it will use an HD video camera that has three tiny video cameras at the lens(Trinocular imaging) to capture three precise views of the tooth. Then the distances between two data points are simultaneously calculated from two perspectives to determine the 3D data, which captured in a video and sequence in real time **(Kravitz et al., 2014)(Figure 1.13)**.

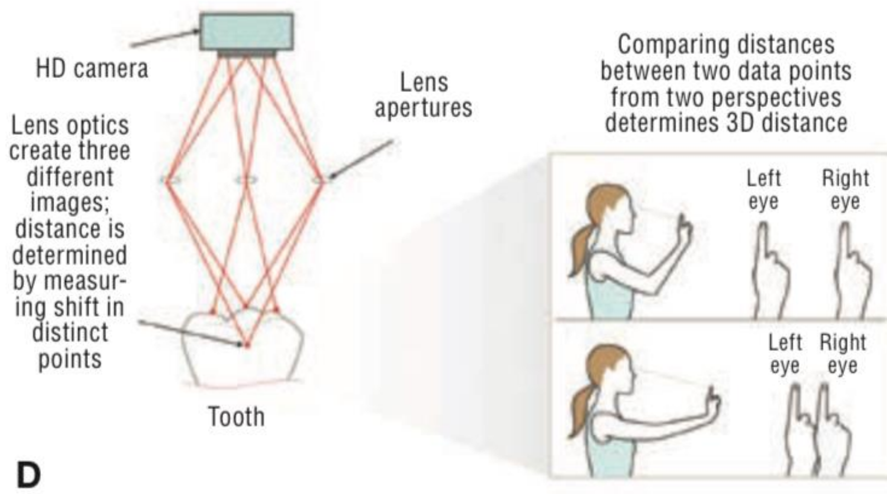


Figure 1.13: Three dimensional in motion video technology (Kravitz et al., 2014)

1.1.6 Methods of obtaining digital impressions

There are two methods of obtaining digital impressions:

1. Indirect or bench top scans of plaster gypsum models: It involves scanning of the casts that obtained by traditional impression techniques **(Guth et al., 2016)**.It has limitations like dependence on obtaining impression of alginate or polyvinyl siloxane to fabricate the cast that will then scanned **(Latham, 2018).**
2. The direct or chair side scans: It is the method which is usually used in the clinic. It uses Intra oral scanners by which we can avoid many of the steps required to obtain the traditional or indirect one**(Guth et al., 2016).**

1.1.7 Scanning technique

1.1.7.1 Scanning path

The scanning path is the specific movement that the scanner should be used in to get the required accuracy **(Zimmermann et al., 2015).** Recent studies have shown the influence of the scan path on the accuracy of data captured using confocal scanners, both in vitro and in vivo **(Müller et al., 2016).** The clinician should preserving the tooth in the center, smooth movement nd steady distance during recording process**(Richert et al., 2017)**. Depending on each scanner and technology, the camera should be held in a range of between 5-30 mm of the scanned surface**(Logozzo, Kilpelä, et al., 2014; Logozzo, Zanetti, et al., 2014a; Zimmermann et al., 2015b)**. In some area like during the change of axis from posterior to anterior tooth and especially in malposed teeth, this maintenance of such path during handling is particularly difficul **(Richert et al., 2017)**. Some manufacturers made a guides to make the practitioners avoiding this difficulties and keep the surrounding tissues out of the camera field**(Richert et al., 2017).**

There are different strategies described by manufacturers for IOS technology **(Richert et al., 2017)**:

The first one is by using linear movement on all occlusal-palatal surfaces**(Figure 1.14 on the right)** Another strategy consists of making S sweep on vestibular , occlusal and lingual faces of each tooth successively **(Figure 1.14 on the lift)**.

Figure 1.14: Scanning bath(Richert et al., 2017)

1.1.7.2 Powdering:

The multiple translucent layers of tooth and restorative material will disperse light at unpredictable angles so some digital scanners require the application of a thin layer of contrast powder coating that also referred to as "dusting" or "accent frosting " over the target tissue. This powder made of opaque mixture of titanium dioxide or less commonly zirconium oxide with amorphous silica and aluminium hydroxide and will applied to the target tissue by handheld spray dispenser blown out in small puffs to deposit a thin layer on the surface to be **scanned (Groth et al., 2014)**. The powdering will provide uniform light dispersion and this will enhance the scanning accuracy. Even scanning systems that are considered powder-free will benefit from powdering especially in regions with poor surface anatomy like mandibular incisors and high translucent porcelain fused to metal crowns and ceramic brackets**(Groth et al., 2014).** Powder-based digital impression has been previously shown to be very accurate for partial Impressions **(Hack & Patzelt, 2015; Patzelt et al., 2014).** However, powder could be relatively uncomfortable for patients, and additional scanning time has been reported when powder is contaminated with saliva during impression as this requires cleaning and reapplication of powder **(Joda & Brägger, 2016)**. Moreover, concerning full-jaw scans, IOS using powder free technologies appears to be recommended due to the difficulty to maintain powder coating on all the teeth for the duration of the scanning **(Zimmermann et al., 2015c).**

Another strategy to overcome this difficulty employed by some systems is to use cameras with a polarising filter**(Burgner et al., 2013)(Figure 1.15).**

Figure 1.15: Powdering (Groth et al., 2014)

1.1.8 Accuracy of Intraoral scanners

Accuracy of Intraoral scanners is an important factor when deciding on which scanner to use in clinical setting **(Latham, 2018).** Recently, greater accuracy has been required for 3D digital models, as they are used not only for diagnosis but also for planning treatments and for the fabrication of orthodontic appliances **(Reuschl et al., 2016)**. Accuracy consists of trueness and precision (Mangano et al., 2017). Trueness or reliability defined as how much the amount of test object or data set are deviates from a reference object or data set **(Latham, 2018).**

Some authors have found that the more complicated area of scanning (such as full arch scan), the more that trueness may be affected. While precision present the repeatability of measurements that's mean it shows how much each test varies from the last object **(Müller et al., 2016).**

A scanner with high precision delivers more consistent result after repeated scans **(Müller et al., 2016; .Ender & Mehl, 2013)** tested three IOS systems using five scanning strategies, he found that although the IOS devices were capable of high accuracy approximately reported 20.4 micrometers as seen in conventional

PVC impressions , the scanning strategy used still have an impact on the results **(Ender & Mehl, 2013)**.

A recent study by Lim et al investigated the effect of repetitive operator experience on trueness and precision and they found that some scanning systems accuracy could potentially effected by operator experience and although this is less likely in video scanning systems as compared to single image systems, some changes in accuracy were noted **(Lim et al., 2018)**.

Table 1.1: Overall scanner comparison including trueness and precision in microns and scan time in minutes format(Latham, 2018).

Scanner	Trueness (Avg)	Trueness Rank	Precision (Std)	Precision Rank	Scan Time (Avg)	Scan Time Rank
Element	46	1	17	2	3.30	4
Emerald	59	3	8	1	2.12	3
Omnicam	119	4	38	4	2.06	2
Trios	47	2	22	3	1.39	1

Many studies have assessed the accuracy of digital models, of which cast models are the gold standard, for making orthodontic diagnoses and linear measurements **(Leifert et al., 2009; Redlich et al., 2008)**. For linear measurements of tooth size, the mean differences in tooth dimension varied from 0.01 to 0.45 mm between the models **(Fleming et al., 2011; Rossini et al., 2016)**. For measurement of mild tooth crowding, the difference between digital and cast models ranged from 0.19 to 1.19 mm for the digital model **(Redlich et al., 2008; Rossini et al., 2016)**. However, only two studies included samples with different amounts of crowding, and they found an increased discrepancy, up to 3mm, between the digital and plaster models, due to an accumulation of measurement error during the space analysis. The authors speculated that the inaccuracy of digital analysis was due to the difficulty of locating the proper mesiodistal width for the space analysis **(Abizadeh et al., 2012; Redlich et al., 2008; Yoon et al., 2018).**

1.2 Extra oral laser scanners:

Laser 3D scanning technology uses a laser line or single laser point to scan across an object**(Elmoutawakkil & Hacib, 2021; Knoops et al., 2017)**. The main advantages of laser scanners, besides producing accurate 3D facial models, is that they are relatively inexpensive and easy to handle **(Goracci Justine Sigouin, 2023)**. The main disadvantages is the longer capture time and affect the eyes, thus it is inconvenient to use in paediatric cases **(Erten & Yılmaz, 2018b).**

They are non-contact 3D scanners meaning the measurement device does not touch the object. This minimizes measurement interference due to physical contact to ensure better accuracy **(www.Polyga.com)**. They capture a large area of the object at once, which makes the 3D scanning process fast and efficient **(www.Polyga.com)**.

3D scanners consist of:

1) Scan head (or capturing unit): the hardware component of the system.
2) 3D Scanning Software: powers the entire 3D scanning operation. **(Www.polyga.com)**.

The system applies trigonometric triangulation by projecting visible or infrared light on the surface of an object/face and interfering the 3D shape based on the distortion of the projected pattern**(Elmoutawakkil & Hacib, 2021; Knoops et al., 2017).**

They are of two types:

1) Stationary laser scnner**(Figure 2.1)**: That allow for rapid image capture and with regards to facial assessment demonstrated high accuracy and precision **(Amanda Justine Sigouin, 2023)**. These require capturing unit to remain still when taking a 3D scan of an object**(Www.Polyga.com)**.

Figure 2.1: Stationary laser scanner(Crotes, 2022)

2) Portable/handheld laser scanner**(Figure 2.2)**: They require someone to hold the capturing unit and wave it around the object to capture scans**(www.polyga.com)**.

Figure 2.2: Portable laser scanner(Www.shining3d.com)

1.2.1 Applications of Facial Scanners

1. Diagnostic Records and the Virtual Patient**(Figure 2.3)**:

Facial scanners have the potential to digitize and replace conventional extraoral records, analog face bow, occlusal analysis, and diagnostic wax-ups**(Lee et al., 2022)**

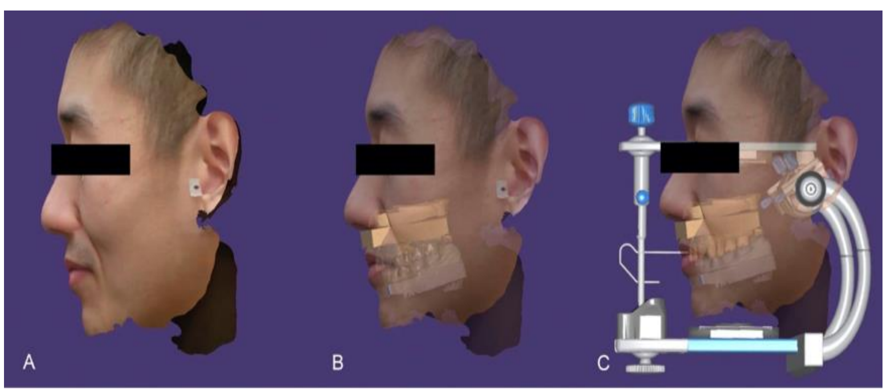


Figure 2.3: Virtual patient (Lee et al., 2022)

Information provided by this virtual patient allows the practitioner to digitally plan treatment across multiple facets of dentistry such as prosthetic and implant rehabilitation, smile design, orthognathic surgery and maxillofacial prosthodontics**(Lee et al., 2022)**.

This system provides information that facilitates digital communication between providers, patients and laboratory technicians in order to achieve a more predictable end result**(Lee et al., 2022)**.

2. Smile Design: In the past, smile design was done in 2D by physically cutting and annotating printed photographs in order to simulate desired final results of treatments and the 2D plans would then be converted into a 3D model through an additive wax up, which was transferred to the patient via a physical mock-up**(Antolín et al., 2018)**. The greatest drawback of such multi-step analog conversions is the risk of introducing error and distortion into the workflow**(Antolín et al., 2018)**. With advances in technology and digital cameras, digital smile design protocols and systems were created to be used in conjunction with Keynote, PowerPoint, or specialized programs to streamline the design process and make the final results more predictable **(Lee et al., 2022)**. In digital workflows with facial scanners, the patient's facial features are recorded digitally, and the conversions that were once done by hand can be done virtually, eliminating the introduction of those errors**(Lin et al., 2018)**.
3. Face scanners make it possible to get a 3D topography of the facial surface anatomy, recognise facial landmarks automatically, and analyse the symmetry and proportions of the face**(Baxi et al., 2022)**. They may be used to monitor growth and development, ethnicity and gender disparities, and identify key diagnostic traits in selected groups of people with craniofacial anomalies**(Baxi et al., 2022)**.
4. Dental long term clear resin: In class II a long term biocompatible resin for printing rigid splint, durable orthodontic appliances, and night guards. This

resin may be suitable for clear aligner direct 3D printing because it has good geometric precision and comparable mechanical properties to thermoforming aligners **(Bourzgui, 2022).**

1.2.2 Advantages and limitations of extra oral scanners

1.2.2.1 *Stationary 3D scanners versus handheld 3D* scanners

Stationary systems have the advantage of being stable, which allows faster image capture, and thus reduces the effect of any motion artefacts, while Handheld scanners have the benefit of being highly portable, however, involuntary facial movements of the subject can be magnified due to the prolonged scanning time and unstable movements of the scanner **(Elmoutawakkil & Hacib, 2021)**. If we want better scan data quality, stationary structured-light 3D scanners outperform handheld 3D scanners, in terms of accuracy and resolution. The reason is handheld 3D scanners capture scans like a video camera, so they capture a scan while the 3D scanner is moving**(www.polyga.com)**.

2 Chapter two: Discussion

The IOS are first of all more accurate than the traditional impressions, They have better impact on the patient and produce more acceptable experience to them and on the other hand more comfortable clinical workflow to the dentist and especially to the Orthodontist.

According to the available data, it is important to embrace the digital era in orthodontics, with the rapid development and advanced research of diverse technologies and compatible materials, it is possible to obtain single scan digital impressions, virtually design, and 3D print different types of orthodontic appliances. 3D facial imaging further provides comprehensive analysis as an aid in orthodontics, maxillofacial, plastic, and aesthetic surgery. Software integration of digital models, 3D facial scans, and CBCT facilitate treatment simulations and establish a meaningful communication with patients.

Elimination of traditional impressions and dental-cast production stages enhance practice efficiency, patient and staff satisfaction for a fully integrated digital and streamlined workflow. Patient digital impressions are stored in a more convenient way and can be easily transferred to any lab or an in-office milling machine for a simpler, faster, and more predictable appliance fabrication. New companies, scanner and printer models are emerging daily which result in significant decline of systems cost and enhancement of material qualities.

From imaging to product design and manufacture, technologies will offer more affordable and feasible diagnostic and treatment applications beyond the current methods.

3 Chapter Three: Conclusions and Suggestions

3.1 Conclusions

- 3D laser scanning can open a new era in orthodontics.

- Orthodontics should be encouraged to include the digital work flow in their clinical practice.

- Laser scanners are the most accurate scanners.

- Limitations should be considered before using laser scanners.

3.2 Suggestions

- Investigation of the long-term outcomes of orthodontic treatment using laser scanning: While laser scanning has been shown to be effective in short-term treatment outcomes, more research is needed to determine the long-term effects of treatment using laser scanning.

- Integration of laser scanning with other technologies: Orthodontic treatments often require the use of multiple technologies, such as digital radiography and 3D printing. Future work could focus on integrating laser scanning with other technologies to create a more seamless treatment experience for patients.

4 References:

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- Abizadeh, N., Moles, D. R., O'Neill, J., & Noar, J. H. (2012). Digital versus plaster study models: how accurate and reproducible are they? *Journal of Orthodontics*, *39*(3), 151–159. https://www.tandfonline.com/doi/abs/10.1179/1465312512Z.00000000023

- Ahlholm, P., Sipilä, K., Vallittu, P., Jakonen, M., & Kotiranta, U. (2018). Digital versus conventional impressions in fixed prosthodontics: a review. *Journal of Prosthodontics*, *27*(1), 35–41. https://onlinelibrary.wiley.com/doi/abs/10.1111/jopr.12527

- Akdeniz, B. S., Aykaç, V., Turgut, M., & Çetin, S. (2022). Digital dental models in orthodontics: A review. In *Journal of Experimental and Clinical Medicine (Turkey)* (Vol. 39, Issue 1, pp. 250–255). Ondokuz Mayis Universitesi. https://doi.org/10.52142/omujecm.39.1.48

- Aljabaa, A. (2021). An overview of applications of digital orthodontic scanners: Unleashing a New era. *Bioscience Biotechnology Research Communications*, *14*(3), 917–921. https://elibrary.ru/item.asp?id=47982019

- Antolín, A. B., Rodríguez, N. A., & Crespo, J. A. (2018). *Digital Flow in Implantology Using Facial Scanner*. Published. http://www.aftdentalsystem.com/wp-content/uploads/2018/03/escanerfacial-GACETAez.pdf

- Antonacci, D., Caponio, V. C. A., Troiano, G., Pompeo, M. G., Gianfreda, F., & Canullo, L. (2022). Facial scanning technologies in the era of digital workflow: A systematic review and network meta-analysis. *Journal of Prosthodontic Research*, JPR_D_22_00107. https://www.jstage.jst.go.jp/article/jpr/advpub/0/advpub_JPR_D_22_00107/_article

-

-B-

- Baxi, S., Shadani, K., Kesri, R., Ukey, A., Joshi, C., & Hardiya, H. (2022). Recent Advanced Diagnostic Aids in Orthodontics. *Cureus*, *14*(11). https://www.cureus.com/articles/122642-recent-advanced-diagnostic-aids-in-orthodontics#!/

- Bourzgui, F. (2022). *Current Trends in Orthodontics*. https://www.intechopen.com/books/10780

- Burgner, J., Simpson, A. L., Fitzpatrick, J. M., Lathrop, R. A., Herrell, S. D., Miga, M. I., & Webster III, R. J. (2013). A study on the theoretical and practical accuracy of conoscopic holography-based surface measurements: toward image registration in minimally invasive surgery. *The International Journal of Medical Robotics and Computer Assisted Surgery*, *9*(2), 190–203. https://onlinelibrary.wiley.com/doi/abs/10.1002/rcs.1446

- Burhardt, L., Livas, C., Kerdijk, W., van der Meer, W. J., & Ren, Y. (2016). Treatment comfort, time perception, and preference for conventional and digital impression techniques: A comparative study in young patients. *American Journal of Orthodontics and Dentofacial Orthopedics*, *150*(2), 261–267. https://www.sciencedirect.com/science/article/pii/S0889540616300622

-C-

- Chochlidakis, K. M., Papaspyridakos, P., Geminiani, A., Chen, C.-J., Feng, I. J., & Ercoli, C. (2016). Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. *The Journal of Prosthetic Dentistry*, *116*(2), 184–190. https://www.sciencedirect.com/science/article/pii/S002239131600041X

- Christensen, G. J. (2008). The challenge to conventional impressions. *The Journal of the American Dental Association*, *139*(3), 347–349. https://jada.ada.org/article/S0002-8177(14)61444-6/fulltext

- Christensen, L. R., & Cope, J. B. (2018). Digital technology for indirect bonding. *Seminars in Orthodontics*, *24*(4), 451–460. https://www.sciencedirect.com/science/article/pii/S1073874618300677

- Christopoulou, I., Kaklamanos, E. G., Makrygiannakis, M. A., Bitsanis, I., Perlea, P., & Tsolakis, A. I. (2022). Intraoral scanners in Orthodontics: A critical review. *International Journal of Environmental Research and Public Health*, *19*(3), 1407. https://www.mdpi.com/1660-4601/19/3/1407

- Ciuffolo, F., Epifania, E., Duranti, G., De Luca, V., Raviglia, D., Rezza, S., & Festa, F. (2006). Rapid prototyping: a new method of preparing trays for indirect bonding. *American Journal of Orthodontics and Dentofacial Orthopedics*, *129*(1), 75–77. https://www.sciencedirect.com/science/article/pii/S0889540605011017

- Cortes, A. R. G. (2022). *Digital Dentistry: A Step-by-Step Guide and Case Atlas*. John Wiley & Sons. https://books.google.iq/books?hl=en&lr=&id=0ct6EAAAQBAJ&oi=fnd&pg=PR11&dq=ARTHUR+R.G.+CORTES,+Digital+dentistry,+2022.&ots=yDeGnOTIpc&sig=KXCxXKdFtpsPudMEIBYAzdZL_0I&redir_esc=y#v=onepage&q=ARTHUR%20R.G.%20CORTES%2C%20Digital%20dentistry%2C%202022.&f=false

- Cousley, R. R. J., & Turner, M. J. A. (2014). Digital model planning and computerized fabrication of orthognathic surgery wafers. *Journal of Orthodontics*, *41*(1), 38–45. https://www.tandfonline.com/doi/abs/10.1179/1465313313Y.0000000075

-D-

- De Riu, G., Meloni, S. M., Baj, A., Corda, A., Soma, D., & Tullio, A. (2014). Computer-assisted orthognathic surgery for correction of facial asymmetry: results of a randomised controlled clinical trial. *British Journal of Oral and Maxillofacial Surgery*, *52*(3), 251–257. https://www.sciencedirect.com/science/article/pii/S0266435613005391

- Eastwood, P., Gilani, S. Z., McArdle, N., Hillman, D., Walsh, J., Maddison, K., Goonewardene, M., & Mian, A. (2020). Predicting sleep apnea from three-dimensional face photography. *Journal of Clinical Sleep Medicine*, *16*(4), 493–502. https://jcsm.aasm.org/doi/full/10.5664/jcsm.8246

-E-

- Edition, F. (2018). Life Care Planning and Case Management Handbook. *Harrell, E.R. An Evidence-Based Evaluation of Three-Dimensional Scanning Technology in Orthodontic Practice. Decis*, 17–20. https://opus.bibliothek.uni-wuerzburg.de/frontdoor/index/index/docId/16183

- Elmoutawakkil, D., & Hacib, N. (2021). *Digital workflow for homemade aligner*. https://books.google.iq/books?hl=en&lr=&id=_8CFEAAAQBAJ&oi=fnd&pg=PA111&dq=D.+Elmoutawakkil+and+N.+Hacib,+“Digital+Workflow+for+Homemade+Aligner,”+in+Dentistry,+vol.+9,+F.+Bourzgui,+Ed.+IntechOpen,+2022.+doi:+10.5772/intechopen.100347.&ots=1CVJ55AQi2&sig=qYNyYi3SVc7MmrY6V4uofUDpM6E&redir_esc=y#v=onepage&q&f=false

- Ender, A., & Mehl, A. (2013). Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. *The Journal of Prosthetic Dentistry*, *109*(2), 121–128. https://www.sciencedirect.com/science/article/abs/pii/S0022391313600281

- Erten, O., & Yilmaz, B. N. (2018). Three-Dimensional Imaging in Orthodontics. *Turkish Journal of Orthodontics*, *31*(3), 86–94. https://doi.org/10.5152/TurkJOrthod.2018.17041

- Erten, O., & Yılmaz, B. N. (2018a). Three-dimensional imaging in orthodontics. *Turkish Journal of Orthodontics*, *31*(3), 86. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6124883/

- Erten, O., & Yılmaz, B. N. (2018b). Three-dimensional imaging in orthodontics. *Turkish Journal of Orthodontics*, *31*(3), 86. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6124883/

-F-

- Farkas, L. G., & Deutsch, C. K. (1996). Anthropometric determination of craniofacial morphology. *American Journal of Medical Genetics*, *65*(1), 1–4. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajmg.1320650102

- Felter, M., de Oliveira Lenza, M. M., Lenza, M. G., Shibazaki, W. M. M., & Silva, R. F. (2018). Comparative study of the usability of two software programs for visualization and analysis of digital orthodontic models. *Journal of Dental Research, Dental Clinics, Dental Prospects*, *12*(3), 213. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6231153/

- Fleming, P. S., Marinho, V., & Johal, A. (2011). Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthodontics & Craniofacial Research*, *14*(1), 1–16. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1601-6343.2010.01503.x

-G-

- Gateno, J., Xia, J. J., Teichgraeber, J. F., Christensen, A. M., Lemoine, J. J., Liebschner, M. A. K., Gliddon, M. J., & Briggs, M. E.

(2007). Clinical feasibility of computer-aided surgical simulation (CASS) in the treatment of complex cranio-maxillofacial deformities. *Journal of Oral and Maxillofacial Surgery*, *65*(4), 728–734. https://www.sciencedirect.com/science/article/pii/S0278239106004344

- Goracci, C., Franchi, L., Vichi, A., & Ferrari, M. (2016a). Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. *European Journal of Orthodontics*, *38*(4), 422–428. https://academic.oup.com/ejo/article/38/4/422/1748812?login=false

- Goracci, C., Franchi, L., Vichi, A., & Ferrari, M. (2016b). Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. *European Journal of Orthodontics*, *38*(4), 422–428. https://academic.oup.com/ejo/article/38/4/422/1748812

- Groth, C., Kravitz, N. D., Jones, P. E., Graham, J. W., & Redmond, W. R. (2014). Three-dimensional printing technology. *J Clin Orthod*, *48*(8), 475–485. https://www.researchgate.net/profile/John-Graham-38/publication/265692065_Three-dimensional_printing_technology/links/5eda97474585152945381eaf/Three-dimensional-printing-technology.pdf

- Güth, J.-F., Edelhoff, D., Schweiger, J., & Keul, C. (2016). A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. *Clinical Oral Investigations*, *20*, 1487–1494. https://link.springer.com/article/10.1007/s00784-015-1626-x

-H-

- Hack, G. D., & Patzelt, S. B. M. (2015). Evaluation of the accuracy of six intraoral scanning devices: an in-vitro investigation. *ADA Prof*

Prod Rev, *10*(4), 1–5. https://zahnwerk-fraestechnik.de/wp-content/uploads/2018/09/Genauigkeitsstudie-TRIOS.pdf

- Hazeveld, A., Slater, J. J. R. H., & Ren, Y. (2014). Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. *American Journal of Orthodontics and Dentofacial Orthopedics*, *145*(1), 108–115. https://www.sciencedirect.com/science/article/pii/S0889540613009062

- Hilliard, J. K. (2006). *Automated method for producing improved orthodontic aligners*. Google Patents. https://patents.google.com/patent/US7077646B2/en

- Hong, C., Choi, K., Kachroo, Y., Kwon, T., Nguyen, A., McComb, R., & Moon, W. (2017). Evaluation of the 3d MD face system as a tool for soft tissue analysis. *Orthodontics & Craniofacial Research*, *20*, 119–124. https://onlinelibrary.wiley.com/doi/abs/10.1111/ocr.12178

-J-

- Jacobson, A., & White, L. (2007). Radiographic cephalometry: from basics to 3-D imaging. *American Journal of Orthodontics and Dentofacial Orthopedics*, *131*(4), S133. https://www.ajodo.org/article/S0889-5406(07)00194-1/fulltext

- Joda, T., & Brägger, U. (2015). Digital vs. conventional implant prosthetic workflows: a cost/time analysis. *Clinical Oral Implants Research*, *26*(12), 1430–1435. https://onlinelibrary.wiley.com/doi/abs/10.1111/clr.12476

- Joda, T., & Brägger, U. (2016). Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. *Clinical Oral Implants Research*, *27*(12), e185–e189. https://onlinelibrary.wiley.com/doi/abs/10.1111/clr.12600

-K-

- Karatas, O. H., & Toy, E. (2014). Three-dimensional imaging techniques: A literature review. *European Journal of Dentistry*, *8*(01), 132–140. https://www.thieme-connect.com/products/ejournals/abstract/10.4103/1305-7456.126269

- Knoops, P. G. M., Beaumont, C. A. A., Borghi, A., Rodriguez-Florez, N., Breakey, R. W. F., Rodgers, W., Angullia, F., Jeelani, N. U. O., Schievano, S., & Dunaway, D. J. (2017). Comparison of three-dimensional scanner systems for craniomaxillofacial imaging. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *70*(4), 441–449. https://www.sciencedirect.com/science/article/pii/S1748681517300141

- Kravitz, N. D., Groth, C., Jones, P. E., Graham, J. W., & Redmond, W. R. (2014). Intraoral digital scanners. *J Clin Orthod*, *48*(6), 337–347. https://acmerevival.com/wp-content/uploads/2022/09/Intraoral-Digital-Scanners.pdf

-L-

- Latham, J. L. (2018). *Evaluation of the Effect of Scan Strategy on the Accuracy of 4 Intraoral Digital Impression Systems*. https://medica-musc.researchcommons.org/theses/279/

- Lee, J. D., Nguyen, O., Lin, Y.-C., Luu, D., Kim, S., Amini, A., & Lee, S. J. (2022). Facial Scanners in Dentistry: An Overview. *Prosthesis*, *4*(4), 664–678. https://www.mdpi.com/2673-1592/4/4/53

- Lee, S. J., & Gallucci, G. O. (2013). Digital vs. conventional implant impressions: efficiency outcomes. *Clinical Oral Implants Research*, *24*(1), 111–115. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0501.2012.02430.x

- Leifert, M. F., Leifert, M. M., Efstratiadis, S. S., & Cangialosi, T. J. (2009). Comparison of space analysis evaluations with digital models and plaster dental casts. *American Journal of Orthodontics and Dentofacial Orthopedics*, *136*(1), 16-e1. https://www.sciencedirect.com/science/article/pii/S0889540609002273

- Lim, J.-H., Park, J.-M., Kim, M., Heo, S.-J., & Myung, J.-Y. (2018). Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. *The Journal of Prosthetic Dentistry*, *119*(2), 225–232. https://doi.org/10.1016/j.prosdent.2017.05.002

- Lin, W.-S., Harris, B. T., Phasuk, K., Llop, D. R., & Morton, D. (2018). Integrating a facial scan, virtual smile design, and 3D virtual patient for treatment with CAD-CAM ceramic veneers: A clinical report. *The Journal of Prosthetic Dentistry*, *119*(2), 200–205. https://www.sciencedirect.com/science/article/pii/S0022391317302081

- Logozzo, S., Kilpelä, A., Mäkynen, A., Zanetti, E. M., & Franceschini, G. (2014). Recent advances in dental optics–Part II: Experimental tests for a new intraoral scanner. *Optics and Lasers in Engineering*, *54*, 187–196. https://www.sciencedirect.com/science/article/abs/pii/S0143816613002406

- Logozzo, S., Zanetti, E. M., Franceschini, G., Kilpelä, A., & Mäkynen, A. (2014a). Recent advances in dental optics–Part I: 3D intraoral scanners for restorative dentistry. *Optics and Lasers in Engineering*, *54*, 203–221. https://www.sciencedirect.com/science/article/abs/pii/S0143816613002339

- Logozzo, S., Zanetti, E. M., Franceschini, G., Kilpelä, A., & Mäkynen, A. (2014b). Recent advances in dental optics–Part I: 3D intraoral scanners for restorative dentistry. *Optics and Lasers in Engineering*, *54*, 203–221. https://www.sciencedirect.com/science/article/pii/S0143816613002339

-M-

- Mangano, F., Gandolfi, A., Luongo, G., & Logozzo, S. (2017). Intraoral scanners in dentistry: a review of the current literature. *BMC Oral Health*, *17*(1), 1–11. https://bmcoralhealth.biomedcentral.com/articles/10.1186/s12903-017-0442-x

- Monpellier, V. M., de Vries, C. E. E., Janssen, I. M. C., van der Beek, E. S. J., van der Molen, A. B. M., Hoogbergen, M. M., & van der Lei, B. (2020). The BAPRAS screening tool for reimbursement in a postbariatric population. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *73*(6), 1159–1165. https://www.sciencedirect.com/science/article/pii/S1748681520300619

- Müller, P., Ender, A., Joda, T., & Katsoulis, J. (2016). Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. *Quintessence International*, *47*(4). https://web.s.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00336572&AN=115168661&h=x50pwQbh66u%2bm0BiAeJgV%2fpNBZzkCu7RghBYeNM9IS7lvsS331TAoY3AV4nNmDaQ9sodiJjKh1zpgpjaPJ2jhA%3d%3d&crl=c&resultNs=AdminWebAuth&resultLocal=ErrCrlNotAuth&crlhashurl=login.aspx%3fdirect%3dtrue%26profile%3dehost%26scope%3dsite%26authtype%3dcrawler%26jrnl%3d00336572%26AN%3d115168661

-N-

- Nguyen, C. X., Nissanov, J., Öztürk, C., Nuveen, M. J., & Tuncay, O. C. (2000). Three-dimensional imaging of the craniofacial complex. *Clinical Orthodontics and Research*, *3*(1), 46–50. https://onlinelibrary.wiley.com/doi/abs/10.1034/j.1600-0544.2000.030108.x

-P-

- Patzelt, S. B. M., Lamprinos, C., Stampf, S., & Att, W. (2014). The time efficiency of intraoral scanners: an in vitro comparative study. *The Journal of the American Dental Association*, *145*(6), 542–551. https://www.sciencedirect.com/science/article/pii/S0002817714601136

- Pekka, A., Kirsi, S., Pekka, V., Minna, J., & Ulla, K. (2018). *Digital Versus Conventional Impressions in Fixed Prosthodontics: A Review*. https://erepo.uef.fi/handle/123456789/7461

- Peluso, M. J., Josell, S. D., Levine, S. W., & Lorei, B. J. (2004). Digital models: an introduction. *Seminars in Orthodontics*, *10*(3), 226–238. https://www.sciencedirect.com/science/article/pii/S1073874604000349

-R-

- Redlich, M., Weinstock, T., Abed, Y., Schneor, R., Holdstein, Y., & Fischer, A. (2008). A new system for scanning, measuring and analyzing dental casts based on a 3D holographic sensor. *Orthodontics & Craniofacial Research*, *11*(2), 90–95. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1601-6343.2007.00417.x

- Reuschl, R. P., Heuer, W., Stiesch, M., Wenzel, D., & Dittmer, M. P. (2016). Reliability and validity of measurements on digital study models and plaster models. *European Journal of Orthodontics*, *38*(1), 22–26. https://academic.oup.com/ejo/article/38/1/22/2599883

- Rheude, B., Lionel Sadowsky, P., Ferriera, A., & Jacobson, A. (2005a). An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. *The Angle Orthodontist*, *75*(3), 300–304. https://meridian.allenpress.com/angle-orthodontist/article/75/3/300/58215/An-Evaluation-of-the-Use-of-Digital-Study-Models

- Rheude, B., Lionel Sadowsky, P., Ferriera, A., & Jacobson, A. (2005b). An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. *The Angle Orthodontist*, *75*(3), 300–304. https://meridian.allenpress.com/angle-orthodontist/article/75/3/300/58215/An-Evaluation-of-the-Use-of-Digital-Study-Models

- Richert, R., Goujat, A., Venet, L., Viguie, G., Viennot, S., Robinson, P., Farges, J.-C., Fages, M., & Ducret, M. (2017). Intraoral scanner technologies: a review to make a successful impression. *Journal of Healthcare Engineering*, *2017*. https://www.hindawi.com/journals/jhe/2017/8427595/

- Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. L. (2016). Diagnostic accuracy and measurement sensitivity of digital models for orthodontic purposes: A systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics*, *149*(2), 161–170. https://www.sciencedirect.com/science/article/pii/S0889540615011750

-S-

- Seo, K., Kim, S., KwonNone, J.-H., & Chang, J.-S. (2017). Implant digital impression with intraoral scanners: A literature review. *Journal of Implantology and Applied Sciences*, *21*(1), 2–13.

- Taneva, E., Kusnoto, B., & Evans, C. A. (2015). 3D scanning, imaging, and printing in orthodontics. *Issues in Contemporary Orthodontics*, *148*(5), 862–867. https://books.google.iq/books?hl=en&lr=&id=ommQDwAAQBAJ&oi=fnd&pg=PA147&dq=E.+Taneva,+B.+Kusnoto,+and+C.+A.+Evans,+“3D+scanning,+imaging,+and+printing+in+orthodontics,”+Chapter+9+Issues+in+Contemporary+Orthodontics,+pp.+147–188,+2015.&ots=hNUDTwf6TZ&sig=ln_v-LB3RctSAE__oR7QAdkYBQM&redir_esc=y#v=onepage&q&f=false

-T-

- Ting-shu, S., & Jian, S. (2015). Intraoral digital impression technique: a review. *Journal of Prosthodontics*, *24*(4), 313–321. https://onlinelibrary.wiley.com/doi/abs/10.1111/jopr.12218

-W-

www.orthopracticeus.com/indirect-bonding-2-0/

www.sciencedirect.com/science/article/abs/pii/S1761722720301170

www.orthodonticproductsonline.com/clinical-tips/treatment-plan-digitally-streamline-%E2%80%A8debanding-retentionusing-digital-impressions-near-end-treatment-ensure-better-retention-results/

www.shining3d.com/blog/handheld-3d-scanner-light-sources-laser-lines-vs-structured-light-vs-infrared/

-Y-

- Yoon, J. H., Yu, H.-S., Choi, Y., Choi, T.-H., Choi, S.-H., & Cha, J.-Y. (2018). Model analysis of digital models in moderate to severe crowding: in vivo validation and clinical application. *BioMed Research International*, *2018*. https://www.hindawi.com/journals/bmri/2018/8414605/

- Yuzbasioglu, E., Kurt, H., Turunc, R., & Bilir, H. (2014). Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health*, *14*(1), 1–7. https://bmcoralhealth.biomedcentral.com/articles/10.1186/1472-6831-14-10

-Z-

- Zahnd, W. E. (2018). *Disparities in breast cancer subtype, staging, and access to mammography services in the Lower Mississippi Delta Region*. https://www.ideals.illinois.edu/items/107025

- Zimmermann, M., Mehl, A., Mörmann, W. H., & Reich, S. (2015a). Intraoral scanning systems-a current overview. *International Journal of Computerized Dentistry*, *18*(2), 101–129. https://europepmc.org/article/med/26110925

- Zimmermann, M., Mehl, A., Mörmann, W. H., & Reich, S. (2015b). Intraoral scanning systems-a current overview. *International Journal of Computerized Dentistry*, *18*(2), 101–129.

- Zimmermann, M., Mehl, A., Mörmann, W. H., & Reich, S. (2015c). Intraoral scanning systems-a current overview. *International Journal of Computerized Dentistry*, *18*(2), 101–129. https://europepmc.org/article/med/26110925