Digital orthodontic treatment planning

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DIGITAL ORTHODONTIC TREATMENT PLANNING

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Proclamation or Dedication or Thanks

I want to dedicate this thesis to my mom, who has always supported me and my dreams and worked hard to make this dental school education possible. I also want to thank all the people I met and lost on this seven-year journey who inspired me and broadened my horizons.

DIGITAL ORTHODONTIC TREATMENT PLANNING

Summary

Digital dentistry is a rapidly evolving field focusing on computerizing and automatizing diagnostic and treatment planning tools. It comprises systems and machines, like oral and facial scanning devices, CBCT, CAD/CAM machines, and 3D printers, that use various techniques and software that help convert, measure, and materialize the captured data. It has become immersed in a daily orthodontic routine worldwide as it addresses multiple challenges. Dentistry has witnessed notable improvements due to their implementation. For instance, dental model analysis, cephalometric measurements, photography, and individualized treatment planning have all experienced significant advancements in digital dentistry. The field of orthodontic techniques in dentistry is vast, covering various areas within the emerging digital dentistry paradigm. This thesis is a narrative review aiming to present the components and steps of digital orthodontic treatment and report on the available data regarding the use and application of digital technology in orthodontics. In doing so, relevant information will be gathered from existing literature to emphasize current clinical trends, research advances, and future applications of digital technology in orthodontics.

Moreover, the thesis clarifies its constraints and potential future developments. Therefore, it is necessary to briefly discuss the technical aspects of scanner and 3D printing machinery and their use. Thus, this thesis offers a concise overview of dentistry's relevant digital systems and tools and their implications for various field areas.

Keywords: digital dentistry; orthodontics; treatment planning

DIGITALNO PLANIRANJE ORTODONTSKOG LIJEČENJA

Sažetak

Digitalna stomatologija brzorastuće je polje stomatologije koje se usmjerava na kompjuterizaciju i automatizaciju dijagnostičkih alata i onih za planiranje liječenja. Sastoji se od sustava i strojeva kao što su oralni i facijalni skeneri, CBCT, CAD/CAM strojevi i 3D printeri, koji se koriste različitim tehnikama i softverima, a koji pomažu u konverziji, mjerenju i materijalizaciji prikupljenih podataka. Zbog svojih višestrukih pogodnosti, digitalna stomatologija postala je dijelom svakodnevnice u ortodonciji, pružajući bolji ishod terapije. Zahvaljujući napretku tehnologije i primjeni navedenih tehnika, stomatologija se razvija velikom brzinom i doživljava znatna poboljšanja. Primjerice, analiza dentalnih modela, cefalometrijska mjerenja, fotografija i individualizirano planiranje liječenja doživjeli su znatni napredak razvitkom digitalne stomatologije. Svrha ovog rada bila je dati pregled digitalnog ortodontskog liječenja te dostupnost podataka o primjeni digitalne tehnologije u ortodonciji. Prikupljanjem relevantnih informacija iz već postojeće literature naglasit će se trenutačni klinički trendovi, istraživački napreci i buduće primjene digitalne tehnologije u ortodonciji koje će zasigurno doprinjeti daljnjem napretku u ovom polju stomatologije.

Ključne riječi: digitalna stomatologija, ortodoncija, planiranje liječenja.

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List of abbreviations

STL – Stereolithographic/Standard Tessellation Language

CT – Computer-aided tomography

CBCT – Cone beam computer tomography

MD – Mesial-distal

CP2 – Canine, first premolar, second premolar

3D – Three-dimensional

CNNs – Convolutional neural networks

IOS – Intraoral Scanners

OCT – Optical coherence tomography

AFI – Accordion fringe interferometry

CAD/CAM – Computer-aided design and computer-aided manufacturing

FDM/FFF – Fused deposition modeling/fused filament fabrication

SLS – Selective Laser Sintering

EBM – Electron Beam Melting

DLP – Digital Light Processing

IDB – Indirect bracket bonding

CoCr – Cobalt Chromium

MARPE – Miniscrew-Assisted Rapid Palate Expansion

TADs – Temporary Anchorage Devices

1. INTRODUCTION

Digital technology in orthodontic treatment is becoming increasingly immersed in routine procedures. This has brought us to the point where classic dental impressions are becoming a thing of the past and are being replaced with intraoral scanners and digital models, cephalography and tooth analysis becoming automatized, and devices designed and printed out within minutes.

It not only makes the workflow of the orthodontists and dental technicians more straightforward, but it also allows patients to be more involved in the treatment planning and the visualization of treatment outcomes. Patients also gain increased comfort and shorter appointments.

This thesis discusses the steps of a wholly digitalized orthodontic workflow, its components, technology, and applications. It touches on components like digital models and their manufacturing, diagnostic tools for obtaining digital data, virtual treatment planning, and 3D printing technology, which we can use for manufacturing digitally designed appliances that are discussed in the last chapter.

2. DIGITAL MODELS

Digital plaster models or dental impressions are obtained using a CT or desktop laser beam scanner. This is called the extraoral or indirect technique. In contrast, we can use the intraoral or direct technique to obtain upper and lower dental arch images stored as STL files. Both techniques enable us to analyze dentition and position of the jaws, make treatment planning, and design appliances (1,2).

1.1. Advantages

- Improvement and elimination of storage problems since, compared to plaster casts, digital models are stored in the form of computer files.
- Easier accessibility and transferability for appointments and in case of a multidisciplinary approach
- Motivation and patient cooperation in orthodontic planning
- Possibility of magnification and anatomic point localization
- Dental and skeletal measurements can be done accurately and semi-automatically
- Possibility of creating a dentofacial model by merging the model with facial scans
- Tracking of the progression of orthodontic treatment with model superimposition
- Fabrication of computer-aided appliances (aligners, custom arch wires, brackets)
- Elimination of discomfort and anxiety from impression-taking in patients
- Rescanning of error areas with no need for another impression, which saves time and materials

1.2. Disadvantages

- In case of the extraoral scanning method, if the plaster casts are poorly done
- In some cases with mixed dentition, the readings of digital imaging can be hard to define and measure
- Need for skills to handle intraoral scanning devices.

Table 1 Comparison of conventional and digital impression-making procedures in dentistry

S. no	**Comparison criteria**	**Conventional dental impression**	**Digital dental impression**
1.	Accuracy	Technique sensitive	Highly efficient and improved
2.	Time consumption	More time-consuming and tedious	Less time consuming
3.	Source of error	Human errors in manipulation and dimensional alteration in impression material	Errors of registration algorithm in obtaining digital scans
4.	Patient compliance	Cumbersome and uneasy for the patient	More comfortable, better compliance
5.	Adverse effects	Alginate allergies and gagging	No such effects seen
6.	Storage and reconstruction	More storage space needed and difficult to reconstruct	Easy and convenient

1.3. Indirect technique

This concept is based on scanning either dental impressions, which represent negative images, or plaster models, which represent positive images, that are then processed either by a commercial provider or by the orthodontic practice itself.

When it comes to approaches for obtaining the images with the indirect technique, reflected energy from the superficial layer of the scanned object is applied in the form of gamma rays, laser, or white light.

The CT is one of the devices that uses this kind of machinery; however, due to depleted resolution and rough surface imaging, there are better choices for generating digital models. Different sources of electromagnetic waves can be generated by a laser, which has a better capacity for generating 3D images from dental stone casts. This comes from the high depth of the laser light field, meaning they can obtain sharp images even through uneven surfaces. Another advantage of laser technology is spectral filters, which help reduce interferences from surrounding light sources. However, the drawback of laser scanning technique is that the entire object cannot be registered from a single sensor position. This slows the image acquisition process since multiple individual scans must be assembled accurately to produce a high-precision 3D model. The last source of the electromagnetic spectrum that can be used for obtaining indirect imaging is the so-called structured light. It uses white light, which permits scanning of total objects in solitary sensor position, saving us time and lowering the possibility of error by eliminating the complex mechanical positioning of numerous scans. Another advantage of white light scanning is that it offers higher surface detail precision, allowing better recognition of structures on study models (1).

When comparing the scanning of the plaster casts to the scanning of alginate/elastomeric impressions, the best dimensional accuracy is achieved with the structured light source on alginate impression, since plaster casts undergo expansion, which leads to minute dimensional changes (1).

Furthermore, any scanner that uses reflection as a source of imaging will, in case of significant overhangs and triangular spaces, as with negative images, result in deficient and imprecise recording (1).

1.4. Direct technique

In contrast to the indirect approach, this technique scans dentition and surrounding structures directly from the patient's mouth. In these cases, we can use CBCT for dental analysis. However, the drawback is ionizing radiation exposure, which increases the dose with the image quality we wish to obtain. To resolve this problem, intraoral scanning systems have been developed to capture entire dental arches (1).

1.4.1. Technical principles

Over the years, many improvements have been made in this field, resolving issues like lagging scanning speed, handiness of the scanning head, and eliminating the need for teeth powdering. The powder coating was used to obtain unified reflectivity, which provided sharper images with increased backscattering, which shortened the retrieval time. This was necessary when the scanning technology used monochromatic perimeters (Cerec® BlueCam). A solution for that was substituting monochromatic perimeters with polychromatic (Cerec® Omnicam), which enabled categorizing each perimeter with less error in case of diminished contrast. Furthermore, the concept that improved shadowing difficulties was based on capturing three images from different angles, which enabled the recording of a 3D figure of an object (LAVA COS®); this resulted in higher scanning precision, but it also necessitated the use of powder, which can present a certain level of discomfort for the patient as well as for the dentist. The True Definition® system, as the progression of LAVA COS®, uses structured illumination with pulsating blue light, which reduces any artifacts occurring with patients' or clinicians' movements; still, due to the use of monochromatic technology, the powdering cannot be eliminated. All the above difficulties were improved by introducing the so-called confocal imaging (iTero®, Trios®), which is based on a laser scanning system using a focused laser probe that does not require contrast agents. Still, new systems need to be developed to improve the speed, accuracy, and reliability of 3D images (2).

1.5. Accuracy

The accuracy of the digital dental models is directly proportional to the type of method we use to obtain them, whether directly or indirectly, using impressions, plaster models or CT, laser, or light scanning. Another factor that needs to be considered is that neither method allows us to obtain the complete dental arch with just one scan, and the need toassemble multiple smaller segments increases the chance for errors. There is a border between clinically significant differences and acceptable variation. Regarding measurements of overjet, overbite, and tooth size (diameter and height), a difference of more than 0.3 mm is treated as clinical significance. In comparison, the transverse and sagittal width is 0.4 mm. The advantage of digitalization is the possibility of magnification and separation, which makes measuring point localization more accrued. However, this can also be dependent on the examiner. Alteration of the models may also result from dimensional changes resulting from the shrinking or expansion of impression materials or plaster (1-3,5).

1.6. Registration of occlusion

Different methods can be used to register occlusion with digital models. One includes scanning the plaster cast models, upper and lower arch from the occlusal aspect individually, and one scan of the models in occlusion from the facial aspect, which enables the reproduction of the occlusal contacts accurately with minimal errors. The second approach can be used by scanning the 3D wax bite record, which requires occlusal surfaces and structures like dental cusps and incisal edges to encounter interocclusal records to be registered, consequently producing more chances for errors in case of lack of contacts. The third method for assessing occlusion with indirect methods is mounting the models in an articulator and scanning them based on reference points that enable calculating the corresponding positions of opposite dental arches. As for the direct methods, this is simplified since we can make the occlusal record directly in the mouth by scanning individual surfaces and then combining them with a locked occlusion scan of patients biting down and remaining still to get accurate positioning (4).

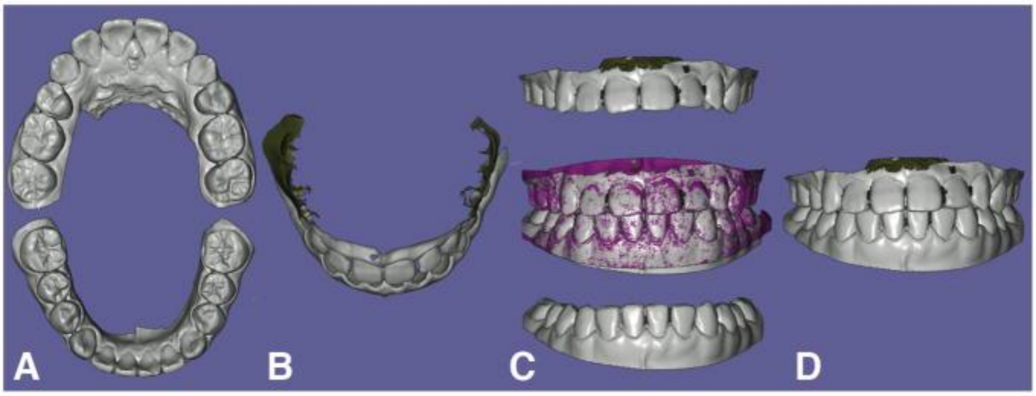

Figure 1 Independently scanned models (*A*) are registered using a scanned surface of the facial aspect of the models in occlusion (*B*). (*C)* and (*D):* The scan of the models in occlusion is used only for the registration of the upper and lower models in occlusion. [Adapted from (4)]

2. DIAGNOSTIC PROCEDURES

The basis for determining the nature of anomaly and therapy planning in orthodontics lies in digital photography, digital model analysis, CBCT imaging, and face scans, which collectively help us form virtual patient records.

2.1. Digital photography

The era of replacing film systems with digital photography started in 2002, and along with it, there was a need for the development of hardware, software, and systems for processing and storing digital data. The advantages that this technology brought include:

- Fast manufacturing of images
- Elimination of errored images
- Removal of film costs
- Easier editing and storage
- Simpler communication
- Accessibility for publications and presentations

During the photography for orthodontic diagnosis, approximately nine pictures are taken. First, we take four extraoral pictures from the frontal view, with the smile, the profile, and at a 45-degree angle. Then, we proceed with five intraoral photographs, starting with the frontal, left, and right, and then the maxilla and mandible from the occlusal view. We help ourselves with retractors and mirror shots to view all the dental structures. Flash is used to improve discernibility when taking intraoral pictures.

This data helps us evaluate the patient's soft tissues, including facial profile characteristics, lip morphology and tonicity, smile line, and Angle class evaluation. It also enables us to follow up on treatment progress and is integral to diagnosis and follow-up (7).

2.2. Digital model analysis

In the past, upper and lower dental arches were analyzed using study plaster casts with the help of a ruler, digital calipers, and wires. With the introduction of digitalization, all these tulles can be eliminated. Instead, we can use computerized software (OrthoCad, Cadent, Fairview) that automatically takes measurements like MD tooth dimension, arch width, arch length, and space analysis. The latest is essential since it predicts crowding and the potential need for extractions. This process includes viewing dissimilarities of tooth widths in the dental arch and line of occlusion, which extends from contact points of molars and premolars, the tips of canines, and the incisal edges of anterior teeth. This marks the span of the dental arch and defines available space (6).

Different kinds of space analysis exist, depending on whether the patient has mixed or permanent dentition. For mixed dentition, we use Moyers and Tanaka Johnson analyses. They both predict the space for permanent dentition based on the sum of the MD width of lower jaw incisors. In Moyer's study, we use prediction tables that estimate the spam of the CP2 segment (8). Tanaka Johnson also uses mandibular incisors sum for prediction since they are more stable than upper incisors. Still, instead of charts, it uses the prediction formula Y = I/2 + 10.5 for the lower arch, Y = I/2 + 11 for the upper arch (I is the sum of incisors and Y is the predicted width of the sum of canine and premolars, on one side of the arch) (9).

Applying this kind of analysis requires specific attention since there might be differences in the space and tooth sizes among various racial and ethnic populations.

The Nance, Lundström, and Bolton analyses are commonly used for permanent dentition analysis. The first two predict dentoalveolar discrepancies, while Bolton is used to anticipate dento-dental variation. The Nance method uses soft wire to determine the length of the dental arch from the mesial surface of the permanent first molar to the mesial surface of the first molar on the other side, which presents the available space. Measuring the MD widths of all teeth in the arch spam, from molar to molar, gives us the required space. After these measurements are obtained, we subtract what is available from the required space, which provides us with the prediction. If the value is negative, this indicates there is a lack of space, which will lead to crowding, while if the value is positive, this will lead to spacing. Lundström's analysis uses a similar principle, but instead of measuring the arch and teeth in one piece, it divides it into six segments. Each segment contains a pair of teeth from the same group (ex., first and second molar). The length of the segment is subtracted from the sums of MD widths of the teeth in the segment. The results are read the same way as the ones from the Nance analysis. As we come to the Bolton type of analysis, in contrast to the two previously mentioned, this one compares the MD widths of teeth from the opposite arches by applying the Bolton formula. The formula defines the overall ratio between upper and lower arch length in percentage, by dividing the sum of MD widths of mandibular teeth by the sum of MD widths of maxillary teeth and multiplying this value by a hundred. If the overall ratio is below 91.3%, the maxillary teeth are more significant than the mandibular ones. If we want to determine only the incisor ratio, we use the anterior ratio formula that uses only six anterior teeth instead of all the teeth in the arch. If the overall ratio in this case is above 77.2%, this points out that mandibular anterior teeth are significantly larger than maxillary. At the same time, if it is below this value, it indicates maxillary incisors excess.

The truthfulness and repeatability of these measurements depend on various elements, such as crowding, tooth inclination and rotation, tightness of the tooth contacts, and shape variations. There will also be differences and variations in measurements between different examiners.

2.3. CBCT imaging

This modality can help us analyze and measure skeletal and dental structures in 3D. It helps us evaluate the arch length discrepancy and perform Bolton tooth size analysis automatically and precisely. With this data, we can choose and predict the type of treatment, which can be based either on serial or later phase extractions, arch expansion, anterior or buccal teeth uprighting, interproximal stripping, and orthognathic surgery. Besides the view of erupted teeth, it also provides clarity regarding the presence and positioning of unerupted or impacted teeth, which assists us in finding the perfect timing to start with orthodontic treatment. The software allows us to test different treatment possibilities and visualize the treatment goals. All of the tooth movements should be made to achieve harmony of soft tissues, occlusal stability, and positioning of the temporomandibular joint (10).

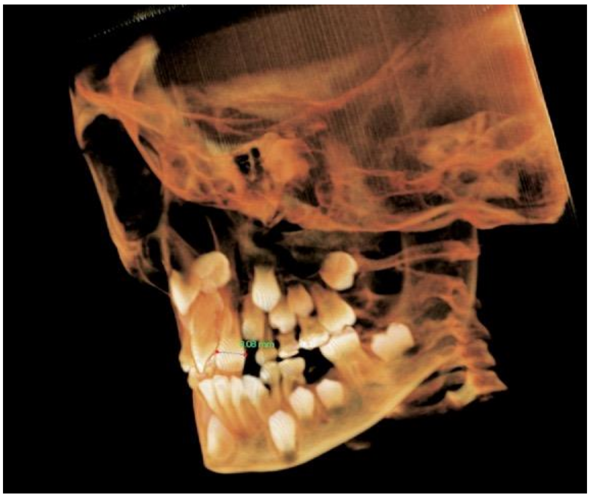

Figure 2 A Cone beam computed tomography scan that helps assess tooth sizes, tooth and root development, arch length, and root proximity. [Adapted from (10)]

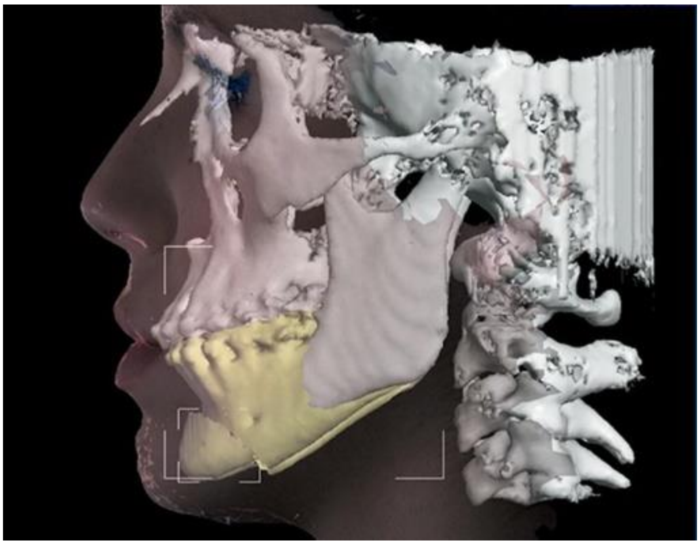

Figure 3 Prediction planning on the CBCT scan for correction of Class III skeletal discrepancy with surgical correction of the mandible by genioplasty and mandibular sagittal osteotomy. [Adapted from (10)]

2.4. Face scans

In addition to skeletal and dental relationships, soft tissue evaluation is equally important and its proportions and relations also need to be analyzed. The 3D view allows a more precise assessment than 2D facial photography when obtaining soft tissue dimensions. Technological advancements have allowed us to merge photographs from different angles that mimic human vision perception. This system is based on stereophotogrammetry and structured lightning electronic components. The structured lightning rebounds from the object's surface and due to unevenness, it distorts and folds. This reflection from various angles is combined to form a three-dimensional picture in the computer software; a process called stereophotogrammetry. The advantage of this system is that it is noninvasive compared to cone-beam tomography. Since there is no or minimal radiation emission, we have a high level of reproduction and straightforward reference point perseverance. The drawback of the system is that imaging will result in errors if the patient has moved or changed the facial expression, which will cause misinterpretation of light (11).

One of the most valued systems, considered the golden standard for capturing soft tissues and tracking changes during the treatment, is the so-called “3dMD Face” (3dMD, Atlanta, GA, USA). It is based on six camera systems placed at different angles and a hand camera that rotates 180 degrees around the patient. These images are combined into a three-dimensional single image stored in the cloud.

The so-called histogram is another feature that can be used when analyzing and processing 3D face images. It presents a pixel intensity distribution within the image. If the intensity is valued on the black and white photographs, it can range from 0 to 255, where the lowest value presents black and the highest white. Regarding color images, the intensity is defined separately for each color, including red, green, and blue. As these values are fixed, they can be displayed in graph form, where the horizontal axis represents the intensity values, and the vertical axis is the frequency of pixels corresponding to these intensities. This data can be used to inspect facial landmarks, texture, age, gender estimation, and face recognition (11).

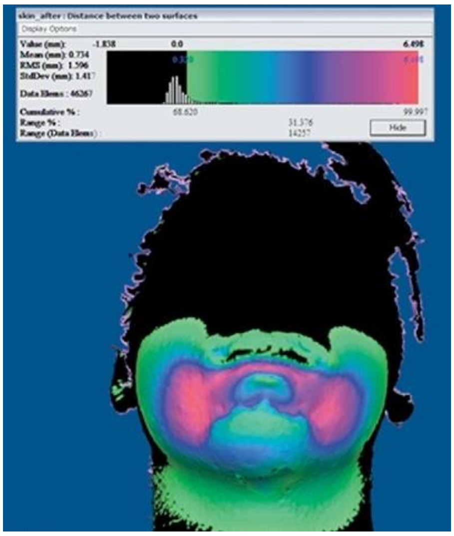

Figure 4 Hologram with graph representation. [Adapted from (10)]

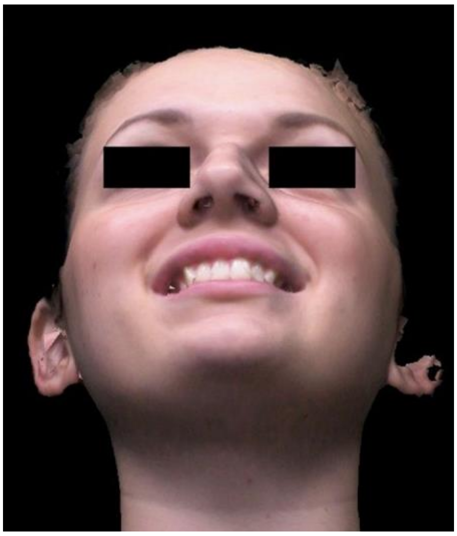

Figure 5 Smiling view of the 3dMD Face scan. [Adapted from (10)]

As smartphone camera technology progresses, the possibility of obtaining three-dimensional face images also exists. This increases the accessibility, lowers the cost, and makes transferring easier (11).

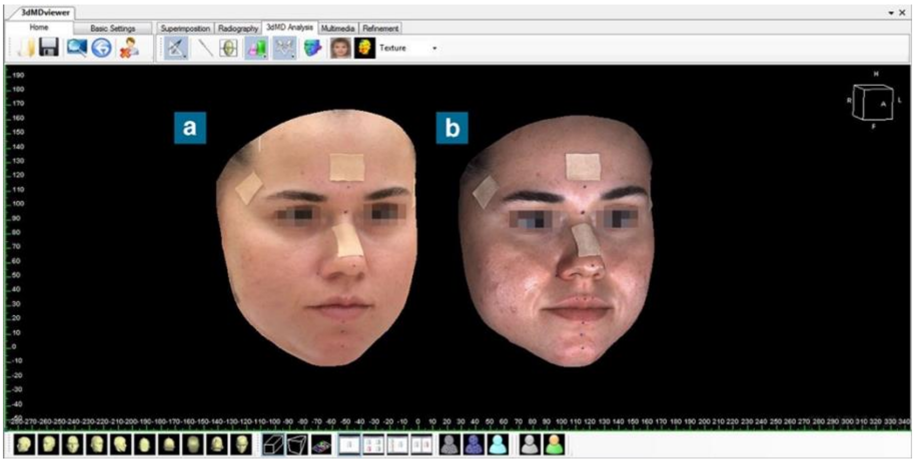

Figure 6 Comparing images taken with a smartphone (a) Bellus3D FaceApp and (b) 3dMD Face technology. [Adapted from (11)]

2.5. Cephalometric analysis

The two primary purposes of cephalography in orthodontics are to define the growth status and to define and measure the landmarks for diagnosis and treatment planning. Initially, the lateral cephalograms were analyzed manually, which was time-consuming and examiner dependent. Later, it became semi-automated because the computer facilitated the process by measuring the distance between manually defined points. As of today, this system is fully automated and can use various approaches that can be divided into four categories:

- Image filtering plus edge-based approach
- Model-based approaches
- Machine learning approaches
- Hybrid approaches

The most recent innovations belong to machine learning, including support vector machines, random forests, decision tree regression voting, and convolutional neural networks (CNNs), which can segment, classify, and detect image layers, edges, and corners (12).
The superimposition, picture quality, and magnification of structures influence the accuracy and reliability of the measurements (13).

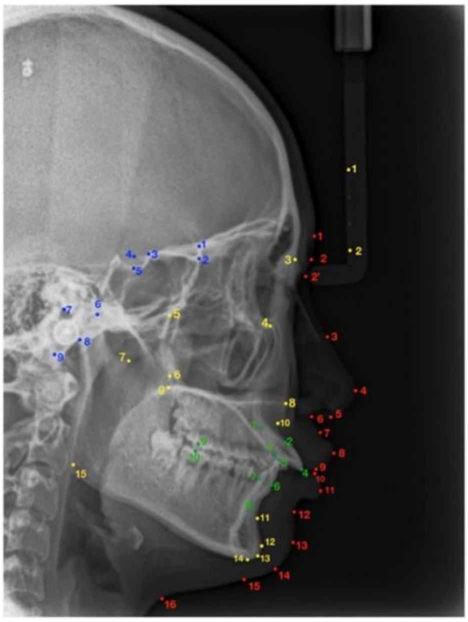

Figure 7 Cephalometric landmarks. [Adapted from (12)]

Besides landmarks, lateral cephalograms are also used to assess skeletal growth based on the cervical vertebrate maturation index. Previously, this was defined by hand-wrist radiography, which required additional radiation exposure. This method appraises changes in borders and shape of the second, third, and fourth cervical vertebrae (C2, C3, C4). The following are chosen since they have the best visibility and similar morphological features. This data is essential in determining the timing of the start of orthodontic treatment by assessing the stage of mandibular growth, as some treatments to modify the growth need to be done before mandibular growth starts and others after the mandibular growth is completed (14).

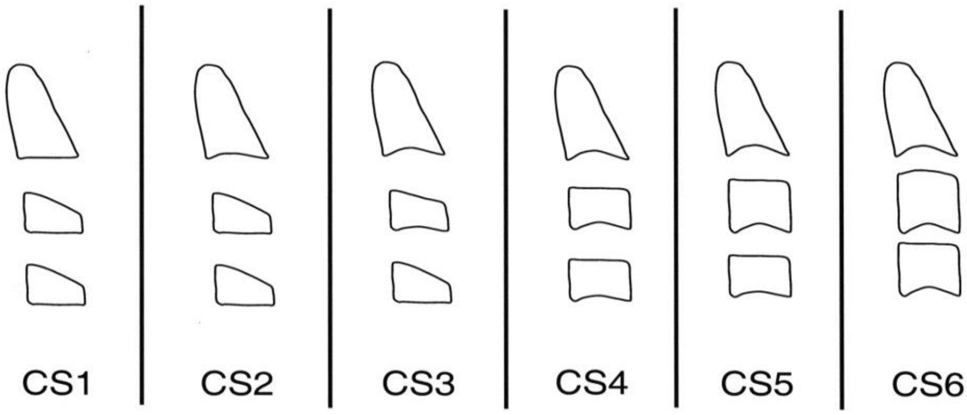

Figure 8 Schematic representation of the stages of cervical vertebrae [Source: Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod. 2005;11(3):119-29.]

3. VIRTUAL TREATMENT PLANNING

With the evolution of technology and easier affordability, more and more steps in orthodontic treatment became computer-guided, making planning smoother, shorter, and more accessible to present to the patient. The workflow can be divided into three parts: intraoral scanning as a first step, followed by 3D model adjustments and planning, and the last step, which includes 3D printing and appliance fabrication (16). It is also widely used in the planning, visualization, and stimulation of orthognathic surgery, where clinicians can perform osteotomies, discuss different treatment strategies, and anticipate facial profiles after correction (17).

3.1. Intraoral scanning

The use of in-office scanning systems began in 2008, with the introduction of Cadent iTero, which captured full arch images, was introduced. IOS are devices that capture optical impressions of dental arches and tissues in a non-invasive way by projecting light onto them. The imaging sensor cameras capture the images from the projected light, which are then sent to the software for processing. The software creates a cloud of polygonal mesh points, representing a three-dimensional (3D) surface model of the teeth and tissue. The mesh is then further processed and refined until a final 3D image of the scanned object is produced (18). This data is then converted into an STL file, which can be easily transferred and shared anywhere globally.

3.1.1. Principles

The basic principle of digital scanning is based on optical phenomena such as optical triangulation, coherence tomography, accordion fringe interferometry, parallel confocal imaging, and 3-dimensional motion video capturing (18).

Optical triangulation

This system comprises a laser-based light source, a high-power lens, and a susceptible sensor plate. All this contributes to the precise measuring of the object’s distance, from millimeters to several microns. The finished surface is irradiated, which creates an image ID on the sensor plate. The accuracy of the scanned surface depends on the inbuilt sensor, which must not come in direct contact with the object. This way, we can capture images of non-dry and soft surfaces (18).

Optical coherence tomography (OCT)

OCT uses light waves for the transmission and projection of high-resolution images. Reflected radiation waves produce natural, life-like images of delicate, defined surfaces with precise measuring scales. It can penetrate tissues up to 3 millimeters deep and is an alternative diagnostic tool for certain medical conditions (18).

Parallel confocal

The laser beam is directed through the pinhole filter, while the receptor sensor unit is placed confocally to the target. The characteristic of this technique is that all unfocused light is canceled, which enables the point and reconstruction mechanism of the scanned images. The slicing and stitching method is applied to obtain a precise image, eliminating unwanted and roaming rays (18).

Accordion fringe interferometry (AFI)

This imaging technique uses two different light sources to project three patterns (fringe pattern). It can be obtained by making a video with a high-resolution camera. Once it hits the object's surface, the pattern is altered, creating a new, unique arrangement, defined as fringe curvature (18).

Three-dimensional in-motion video

It is collected by three miniature video cameras built at the base of the lens. This trinocular technology can capture incredible details of the recorded structure. The distance between two captured points must be determined from two perspectives to obtain the 3D image. The advantage of this technique is that it eliminates the need for powdering. Besides impression taking, it can also be used to fabricate appliances and retainers (18).

3.1.2. Scanning devices

iTero Scanner

It has been on the market since 2007. It is based on the confocal scanning technique, which can capture the minor details of the intraoral structures and anatomical abnormalities such as tori. Due to its small scanning handpiece, it can also be used in patients with limited mouth openings. Its design was improved by making it lighter and steadier to handle in the new version known as iTero Element. It is very fast as well as straightforward to use; the scans of both jaws can be produced in 2–3 minutes and files can easily be shared among offices or with the dental laboratory. Another good feature of this system is that it can be easily stopped and started during scanning as many times as necessary. It can be used to obtain the pre-treatment record, for impression making, appliances and retainers' fabrication, and with Invisalign treatment (19).

TRIOS intraoral scanner

This high-resolution optical scanner was introduced globally in 2010 and it is known for its delicate details of the scanning surface and high-speed technique. It is based on combining multiple smaller pieces of scanned information or the so-called point-and-stitch reconstruction. Since its introduction to the market, many other improved versions have been designed, including a TRIOS Cart with bright screen integration and TRIOS Pod. This transferable form of the scanner can be connected to a laptop, monitor, or iPad. It also comes with a sterilizable removable tip and flexible handle. The files can be easily shared via Wi-Fi or Bluetooth and viewed in scanned or STL form. Combining it with the Ortho Analyzer software, calculations of overjet, crowding, spacing, and arch length can be comprehended (19).

The Lythos TM intraoral scanner

This scanner is one of the accordion fringe interferometry-based intraoral scanner systems and was launched in 2013. It has fast scanning ability and powdering is not needed. The camera is built inside the scanner tip and receives the deflected beam from the scanned surface. This transportable device includes a touchscreen software system and a flexible handle with replaceable tips. Scans are formulated in STL files and can be easily stored for an extended period. Its utilization is possible in the linguistic system and smile design (19).

PlanScan

There are three versions of this USA scanning system: Planmeca, Plan CAD, and Plan Mill, which were presented in 2014. It is based on the blue laser technique and can snatch the image swiftly while allowing you to reconstruct the data later. Its most outstanding feature is that it can be connected to a computer screen via a USB connector. It also has changeable and sterilizable tips, the size of which can be adjusted based on whether we are scanning anterior or posterior surfaces. The compatible software is Planmeca RomexisH 3D Ortho Studio which has basic and advanced mode versions. With the basic version, we can perform treatment planning, while for it to be able to segment and design the virtual setup and simulation, an advanced mode needs to be purchased (19).

Table 2 Commercially available digital scanners with their clinical application in dental practice (18).

S. no	**Scanner**	**Scanning technology**	**Applications**
1.	iTero Scanner	Parallel confocal imaging	- Digital impression making - Fabrication of digital cast, appliances, and retainers
2.	TRIOS Intraoral scanner	Ultrafast Optical Scanning technology	- Intraoral scanning - Extraoral scanning
3.	Lythos TM	Accordion Fringe Interferometry	- Treatment planning - Overjet & overbite measurement - Arch analysis
4.	PlanScan	Blue LASER technology	- Tooth segmentation - Virtual setups

3.2. Virtual orthodontic setup

As discussed in the first chapter, we can perform extra or intraoral scanning to obtain a virtual orthodontic model. Either way we choose, the final result will be a digital model that can be evaluated with the help of computer software. The first step when creating a virtual setup is determining the arch form and tooth axis. This procedure can be done semi-automatically using software like the OrthoAnalyzer, which helps with teeth segmentation. After this is set up, we can proceed with the teeth alignment according to the treatment plan and the application of six keys of occlusion, which are:

- Normal molar interrelationship when in total intercuspation
- Correct crown angulation or mesiodistal inclination
- Correct crown inclination or torque
- No rotations
- No spacing
- Desired occlusal plane

In addition to this, the midline of the teeth arch needs to match the midline of the face and overjet and overbite should rest between 1 and 4 millimeters (17).

Figure 9 Overview of the virtual setup for the maxilla. **a** Semi-automatic determination of the border of each tooth. **b** Segmentation of each tooth. **c** Virtual setup is created by displacing each tooth to create a harmonious arch. [Adapted from (17)]

To gain complete vision and a better perspective, CBCT and face scans can be combined with the models to form a complete virtual patient.

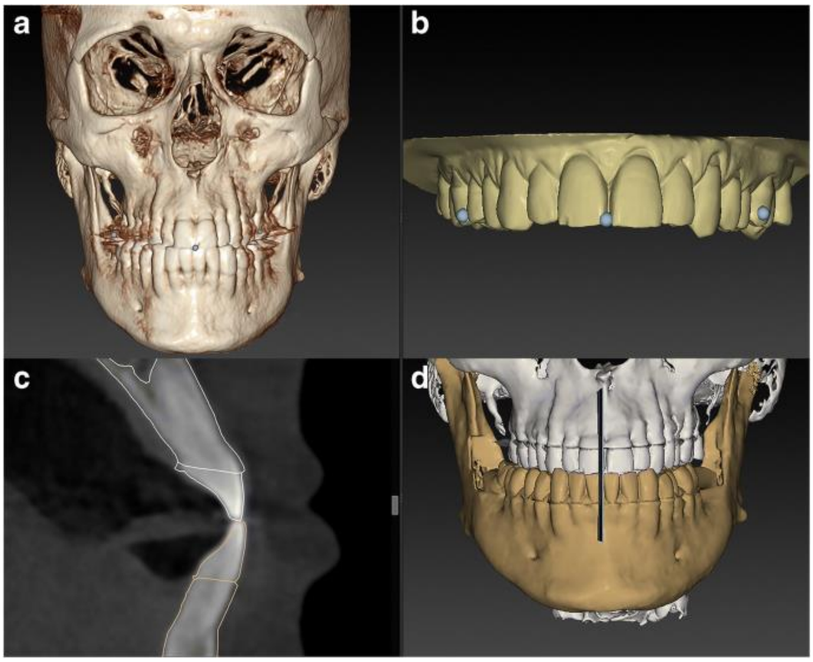

Figure 10 Matching of the intraoral scan with the CBCT scan. The CBCT scan has three dental landmarks. **b** The intra-oral scan with the same dental landmarks as in the CBCT. **c** Cross-section of the result of the fusion. **d** Final result showing the fusion of the intraoral scan with the CBCT. [Adapted from (17)]

To calculate the difference between the pre-treatment model and virtual setup, STL files need to be created and exported into MED software, where we can superimpose the models and calculate the rotation of each tooth in three axes. This is possible due to the 3D surface-based matching (SBM) that helps translate each tooth movement from the pre-treatment model to a virtual setup.

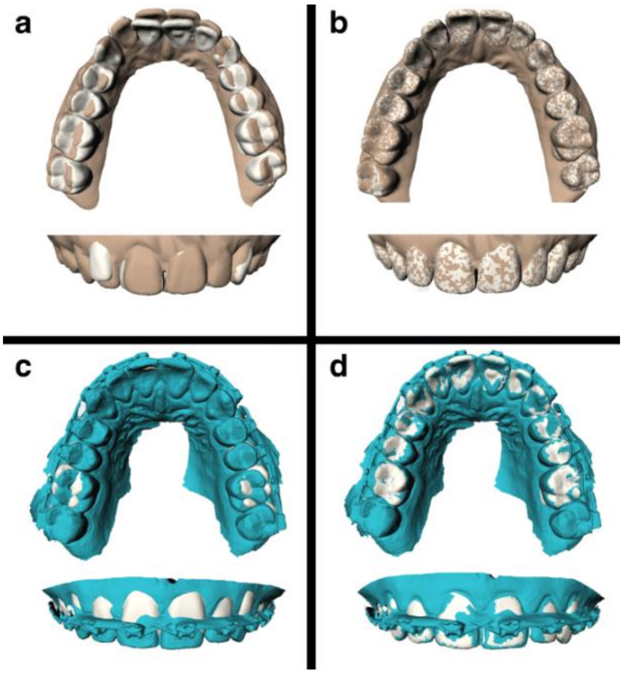

Figure 11 Overview of the different steps to calculate the difference between the virtual setup and the outcome for the maxilla. The same steps are required for the mandible. **a** In brown, the pre-treatment dental arch, and in white, the virtual setup's segmented teeth. **b** Each tooth is matched onto the virtual setup. Translations and rotations for each tooth are recorded. **c** In blue, the outcome, and in white, the virtual setup's teeth. **d** Each tooth (white) is matched to the outcome (blue). The translations and rotations are recorded and the difference between the virtual setup and the outcome can be calculated. [Adapted from (17)]

3.3. 3D printing

3D printing enables the manufacture of objects designed in computer software, which are created by adding material in multiple layers building up on each other. It is a step in the CAD/CAM technology system, which starts with digital data collection, continues with software for processing, and finishes with transforming the digital data into a final product. Before printing, every design should be converted to STL format representing the object's surface geometry, built of many triangles whose peaks represent system coordinates. It belongs to the additive manufacturing method, which contrasts with the so-called subtractive method, where the object is cut from the block of material by removing the excess. The advantages of this technique are that it produces high-quality products with no waste material and is less expensive. It also allows us to print shapes with undercuts and holes, which is impossible with the other method. Materials that can be used with 3D printers include gypsum, metal alloys, carbon fiber, resins, and organic materials like cells and tissues (20).

3.3.1. 3D printing technologies

Stereolithography (SLA)

It is the first printing technology introduced by Charles Hull. It utilizes photocurable liquid resin. The procedure is based on the hardening of each resin layer with a UV laser beam, which initiates polymerization. Once one layer is hardened, the new resin layer is spread, and the procedure repeats until the whole object is constructed. Post-processing is necessary with this technique, and it includes the removal of unpolymerized resin and ultraviolet oven curing to ensure complete polymerization and uniform material with better mechanical properties. With this type of printing, we can produce more complex shapes and designs. However, additional support structures must be incorporated into the design, which are removed after finishing. It is an exact method that achieves high quality and resolution with a shallow thickness of layers (25 µm), establishing a smooth surface without irregularities and layer binding. In dentistry, it is used to fabricate implant surgical guides and orthodontic dental models (20).

Fused deposition modeling/fused filament fabrication (FDM/FFF)

Recently, this has been the most commonly used printing technique that uses thermoplastic materials. By heating it to the melting temperature, the material is layered with the help of extrusion heads in the predefined arrangement. Each deposited layer is integrated as the material hardens. Its advantage is that it does not require post-processing with printing layers that are 127 µm thick. The drawbacks of this technology are shrinkage resulting from cooling and the need for specificity of viscosity and thermoplastic properties of the material. Acrylonitrile butadiene styrene polymer (ABS), polycarbonates (PCA), polylactic acid (PLA), waxes, and polyphenylsulfones are the most used materials for FDM. It is widely used to fabricate aligners and retainers, although it has inferior aesthetic properties due to the stair-stepping effect (20).

Selective Laser Sintering (SLS) and Electron Beam Melting (EBM)

SLS uses glass powder in combination with a CO2 laser beam that sinters the glass particles together in a specific pattern layer by layer. Compared to SLA, this structure requires no additional support during build-up since bounded particles provide sufficient support and stability. Postprocessing involves the removal of excess glass powder particles, which is relatively simple and fast. Powders can be made from polymers like polyamides, polycaprolactone, hydroxyapatite, glass, ceramics, or metal alloys, such as stainless steel, titanium, and cobalt-chromium (20).

Electron beam melting, like SLS, uses powder as a sintering material; however, the energy source to convert it to a solid material comes from an electron beam in a vacuum controlled by a computer. Besides stainless steel and titanium, we can also use copper alloy powders. It is highly used to produce osseointegrated implants since the produced objects have remarkable mechanical properties and high porosity (20).

Digital light processing (DLP)

It is an upgrade of the SLA technology that utilizes faster production and hardening of the photopolymer by projecting the light over the entire layer, not only one spot. This is achieved by using a digital micromirror device (DMD). The precision and thickness of each layer are exceptional, they are around 30 µm thick. Two devices that use this technology are Ultra 3SP Ortho and Perfactory Micro Ortho. They are used to manufacture dental working models for orthodontic appliance fabrication (20).

Inkjet 3D printing (3DP/IJP) and polyjet

The 3DP combines liquid and powder, which is transformed by UV curing, chemical or thermal reaction, or dehydration. It allows the combination of different materials in one object during the printing session. Layer thickness ranges around 12 µm. The production time is shorter than that of FDM; however, the precision is lower than that of stereolithography (20).

Polyjet or polymer jetting implies a printing procedure that uses liquid photopolymer material in which layers are cured by ultraviolet light after spreading on the building platform. It requires additional supporting structures, which are built along with layers of the same material and can be easily removed upon completion. When finished, there is no need for post-curing and removal of the residue. The thickness of the layers ranges between 16 and 32 µm, which makes the method specific enough. Currently presented devices on the market with this technology are Objet30 OrthoDesk, Objet30 Dental Prime, and Objet500 Dental Selection. Depending on the printing material, it can produce orthodontic working and study models, surgical stents, and dental mockups (20).

4. APPLIANCES

Appliances represent another vital field of orthodontics besides diagnostics and orthodontic treatment planning. With the improvement and development of CAD/CAM technology, more customized devices can be printed or milled. This can speed up the production process and increase the preciseness and accuracy of appliances.

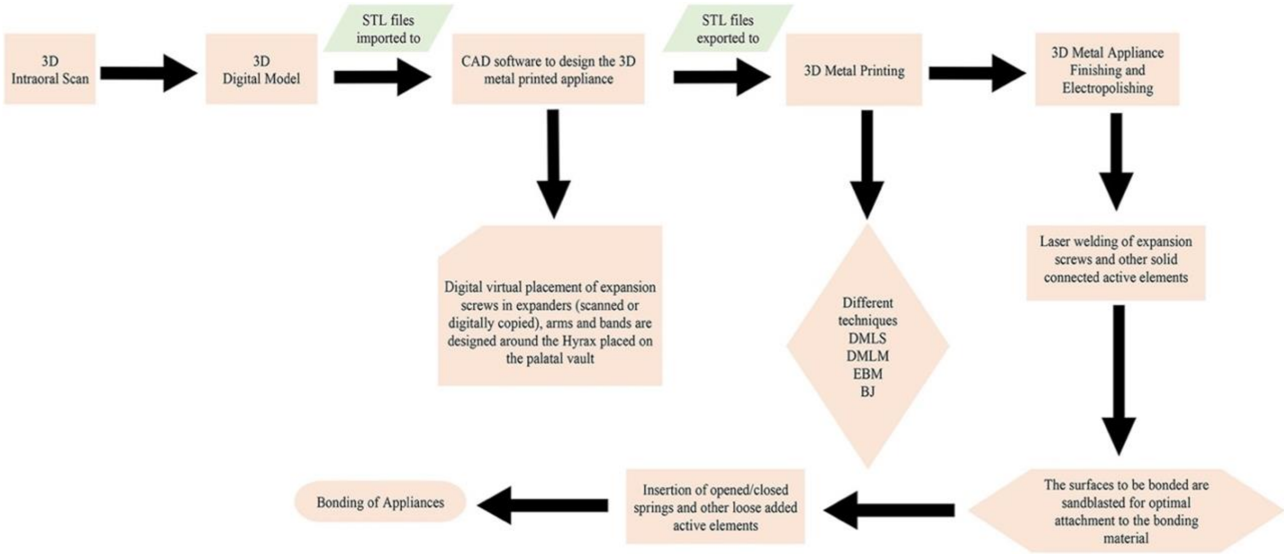

Figure 12 Digital workflow for customized orthodontic appliances. [Adapted from (26)]

4.1. Diagnostic and working orthodontic models

Suppose the whole orthodontic treatment planning flow is conducted digitally to fabricate some appliances such as aligners. In that case, the jaw models are required to be not only digital but also physical. 3D printing technology allows us to make numerous replicas of one model without any risks of distortion and dimensional changes. This can be especially useful in producing thermoformable aligners, where we have to make a sequel of models for each stage of treatment. It can also be applied in manufacturing removable orthodontic appliances, expansion appliances, and indirect bonding trays.

The most crucial factor to be considered when printing the working and diagnostic models is the precision and trueness of selected diagnostic measurements. This can differ depending on the material and method of printing. Research showed the highest precision in PolyJet and DLP models, while stereolithographic models' trueness was the highest when comparing different printing technologies (20).

4.2. Aligners

The popularity of aligners is growing daily due to higher aesthetics, improved oral hygiene, periodontal health, and flexibility for other orthodontic treatment methods. With the rise of its popularity, techniques and technologies have also kept evolving. Different aligner systems differ in materials, production techniques, correctness, and margin finishing. Since planning is wholly digitalized, they can be designed and produced worldwide (21).

Fabrication

We can produce aligners with the help of digital technology in two different ways. Both start with intraoral scanning and are designed using the corresponding software to make orthodontic treatment plans. Each step of tooth movement is saved separately in STL file form, each representing one aligner. The difference lies in the manufacturing step. This can be done by printing models and pressing thermoforming foil over them, or they can be directly designed and printed out using additive methods. Essential characteristics that must be considered regarding the mechanical properties of each type of aligner are the modulus of elasticity and stress relaxation (23). They define stiffness and time dependence as stress decreasing under constant strain. Based on that, the aligner's efficiency and ease of removal are defined. Another factor crucial for the accuracy of tooth movement is the thickness. Directly printed aligners are often significantly thicker compared to the thermoforming technique. Materials used include different types of resin polymers. Polyester, polyurethane, and polypropylene are the predominant thermoplastic materials for fabrication of clear orthodontic appliances (22).

Table 3 Materials employed by commercially available Aligner Companies for thermoforming technique (21).

Aligner Company	**Materials Used for Aligner Manufacture**
Align Technology	Invisalign SmartTrack (Multilayer polyurethane and copolyester proprietary material (released 2013)
ClearCorrect	Specially formulated polyurethane plastic
Dentsply Sirona	Essix plastics
K Line (Europe)	Polyethylene terephthalate glycol-modified and other additives
Exceed Technologies	Recommended: 0.75 mm Biolon (Dreve) or 0.75 mm Duran (Scheu-Dental)
Forestadent	Forestadent Track V (thickness can be changed every third aligner).
Great Lakes Dental Technologies	Invisacryl Ultra Invisacryl Hard/Soft
Scheu-Dental	CA Foils (biocompatible, thermoforming polyethylene terephthalate)
TP Orthodontics	Thermoplastic polymer
Rocky Mountain Orthodontics	Dual-layer polymer with hard outer tray and soft inner tray (thinner aligner for daytime wear, thicker for night)
Smart Moves	Invisacryl: Copolyester proprietary
Ez-Align	Dynaflex: Copolyester
MTM Clear Aligners	Raintree Essix ACE: Copolyester-proprietary

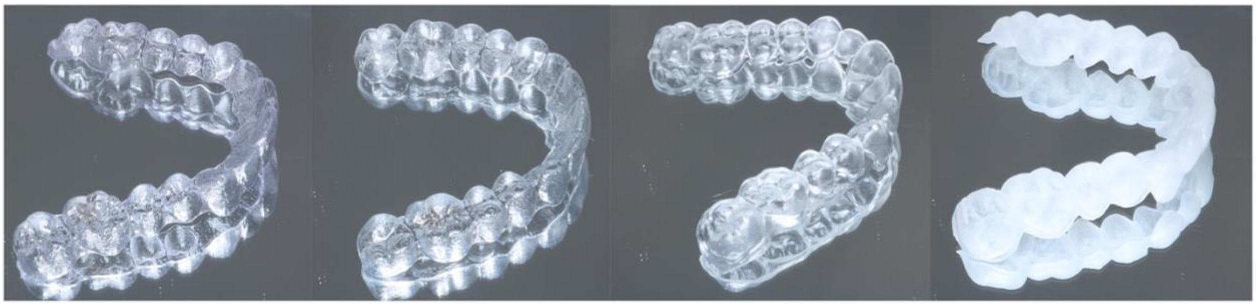

Figure 13 3D-printed orthodontic aligners from left to right: EX30, LD30, Material X, and OD-Clear TF. [Adapted from (22)]

4.3. Customized brackets and bracket trays

With brackets, digital technology can be incorporated by printing customized brackets in resin or zirconia adjusted to teeth' shape and size or by printing them in wax and pressing them in lithium glass ceramics. Placement or bonding on teeth can then be done using the direct technique of placing each bracket individually or with the indirect method of using 3D-printed customized trays where we can bond all the brackets in one arch at once or in segments (23).

The advantage of this technique is the possibility of more accurate and faster orthodontic treatment and the chance of reducing the thickness of the bracket. The brackets can be printed from zirconia or resin material. Both have their advantages and disadvantages. Zirconia brackets have better color stability and aesthetics but harder debonding, while resin-type brackets have lower color stability and aesthetics, easier debonding, and more affordable prices. Before printing, orthodontists create the setup in the software, which positions virtual brackets that will be printed later on teeth. The brackets can be transferred to the teeth with the help of transfer keys or with printed IDB resin trays designed in software like Ubrackets (24).

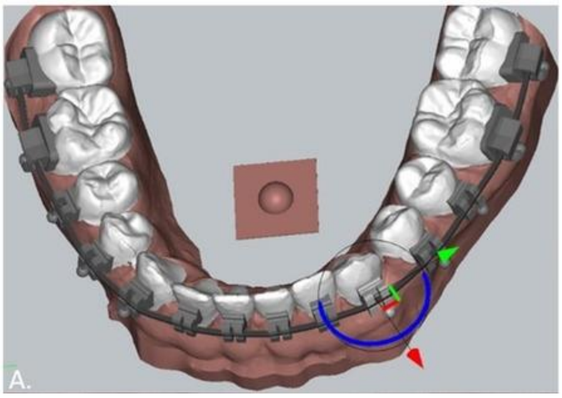

Figure 14 **A** Setup and automatic positioning of customized brackets in Ubrackets software. Setup is the first step in the customization process, followed by the automatic placement of the 0.018 × 0.025 inches slot brackets on a flat 0.018 × 0.025 inches archwire. [Adapted from (24)]

The transfer trays for the indirect bonding technique are designed and produced with the help of CAD/CAM technology and can be made of rigid or medium soft resin material. The rigid trays require a try fitting on the malocclusion models to detect any misfitting and overcome the undercuts, which might present difficulty during removal. In contrast, the semi-soft trays can more easily overcome these challenges (25).

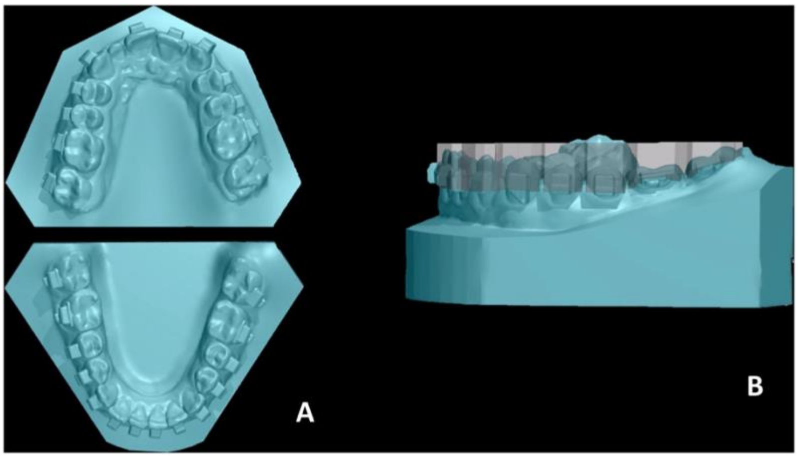

Fig 15 **A** Modified CAD model. **B.** Design and extension of medium-soft, transparent, and almost full-coverage CAD/CAM transfer tray. [Adapted from (25)]

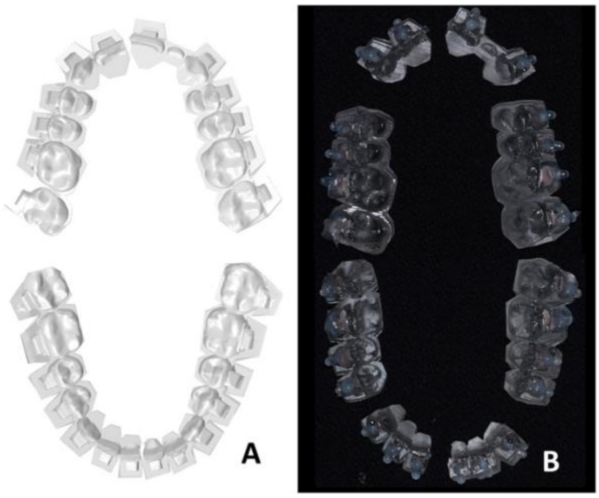

Figure 16 Digital transfer tray CAD **(A)**. 3D CAM printed transfer tray **(B)**. [Adapted from (25)]

4.4. Surgical templates for orthodontic miniscrews and miniplates placement

These appliances serve as a source of intraoral anchorage devices, which, by loading, reduce reaction forces acting on teeth and expand possibilities of tooth movement. The limitations that can compromise stability and force control of the mini screw placement are anatomical variations which can lead to the risk of root damage, perforation of the maxillary sinus, or neurovascular damage. To improve the precision of the miniscrew placement, 3D surgical templates can be printed out from biocompatible material such as ABS (acrylonitrile butadiene styrene). The design uses software that superimposes CBCT images with dentition scan data. Miniplates are an alternative to orthodontic miniscrews when we want to achieve maximum anchorage. Their applications range from maxillary molar intrusion and distalization to open-bite treatment and molar protraction. The important parameters when placing the miniplates are the proximity and adoption of the plate to the bone and correct positioning. This is achieved with a 3D-printed model of patients' bone based on CBCT images. The plate is fixated on this model with mini screws, guiding the fabrication of a jig for transferring the plate to the patient's mouth (20).

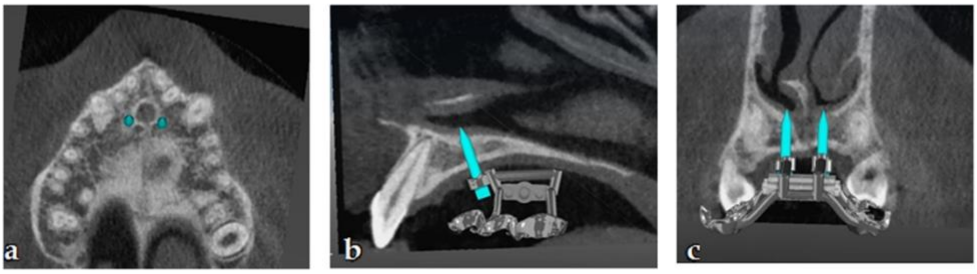

Figure 17 Bicortical anchorage of miniscrews using CBCT guidance in **a** superior, **b** lateral and **c** posterior views. [Adapted from (26)]

4.5. Space maintainers

Space maintainers are devices used in case of premature loss of permanent dentition, to keep space for the eruption of their successors. These appliances are most commonly made of metal like CoCr, which can be made conventionally or with the help of 3D printing technology. By printing SMs, we enhance their mechanical properties and thus make them less favorable to brake under chewing forces. The simplest type of space maintainer is a band and loop. Its design is based on a band, cemented on a tooth, and a loop that extends from the banded tooth across the gap of the missing tooth and makes contact with the opposite tooth in its middle third. The loop occlusally mimics the buccolingual width of the future permanent tooth and follows the gingival contour close to the gingival line without making contact. Other types of space retainers which can be printed include lingual arch, transpalatal arch, and Nance palatal arch. The drawbacks of these devices are food retention and caries formation (26).

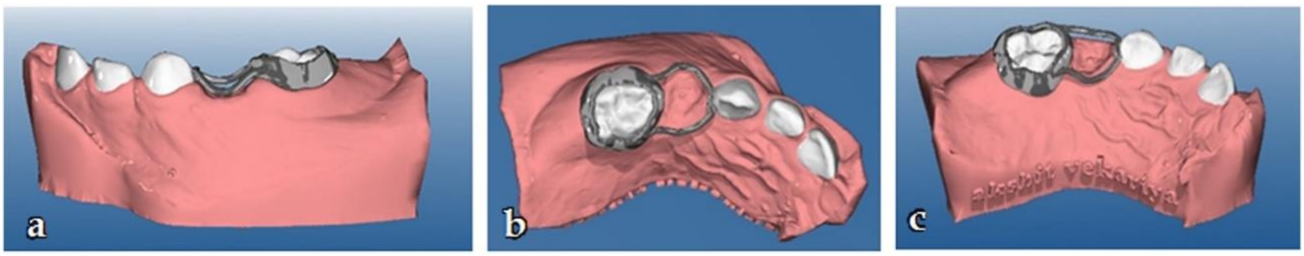

Figure 18 Figs. a, b, and c show the digital design of the space maintainer. [Adapted from (27)]

Figure 19 Lingual arch space maintainer. [Adapted from (27)]

Figure 20 Nance palatal arch space maintainer. [Adapted from (27)]

4.6. Arch expanders

In situations that involve transverse arch problems, such as crossbite, expansion of the maxilla might be performed. The type depends on the stage of development of the midpalatal suture. Based on that, it can be tooth-borne or miniscrew-assisted. In both cases, the flow starts with intraoral scanning of the maxillary arch and uploading the scan to the selected software, where we design arms and bands that will be printed and connected to a prefabricated Hyrax screw. The Hyrax screw digital file design is available in the software or can be ordered from a selected manufacturer. This is necessary to make a perfect fit and adjust the undercuts and bands with the appliance, since it is rigid and will not allow any deviations. Once the framework is printed, the Hyrax screw is attached to it with laser welding. When the midpalatal suture is ossified, after age sixteen, the desired arch expansion cannot be achieved solely with a tooth-borne arch expander. To overcome that challenge, MARPE was introduced. It can be prefabricated; however, various anatomical variations in the palate's height and width limit the therapy's function and success. With the help of digital technology, the engagement and placement of miniscrews can be far more precise using CBCT images superimposed with intraoral 3D scans (26).

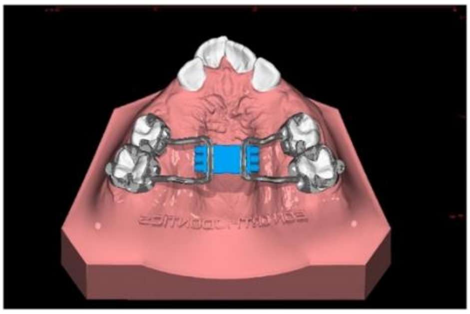

Figure 21 Final Hyrax appliance digital design. [Adapted from (26)]

Figure 22 3D printed framework on a plastic model. [Adapted from (26)]

Figure 23 Laser welded Hyrax appliance after printed metal polishing. [Adapted from (26)]

Figure 24 Various customized designs of MARPE. [Adapted from (26)]

4.7. Distalizers

Molar distalization is the therapy of choice in Class II/1 patients with mild protrusion of the anterior maxillary teeth with contraindication for premolar extraction. Mini implants, placed in the anterior palate, were incorporated into the design of this device to improve and minimize anchorage loss. Two implants are placed into the anterior hard palate, held by an individualized 3D-printed prefabricated framework. The flow includes the placement of the MARPE and TADs with the help of CBCT and intraoral scan overlap. Ideal positioning is in midpalatal and paramedian areas where we can achieve maximum stability due to bicortical engagement. The frame is composed of molar bands that will be cemented and a Hyrax screw that is, contrary to arch expanders placed in the middle of the palate, placed parallel to the dental arch in both occlusal and sagittal views. Its position can be adjusted in sagittal direction depending on whether we wish to achieve intrusion or extrusion. To keep the constant forces, the Hyrax screw is activated two times a week by turning it for a quarter. Alternative to Hyrax, an open coil spring can activate a printed slider assembly. In this case, the spring is activated by 3 mm each visit (26).

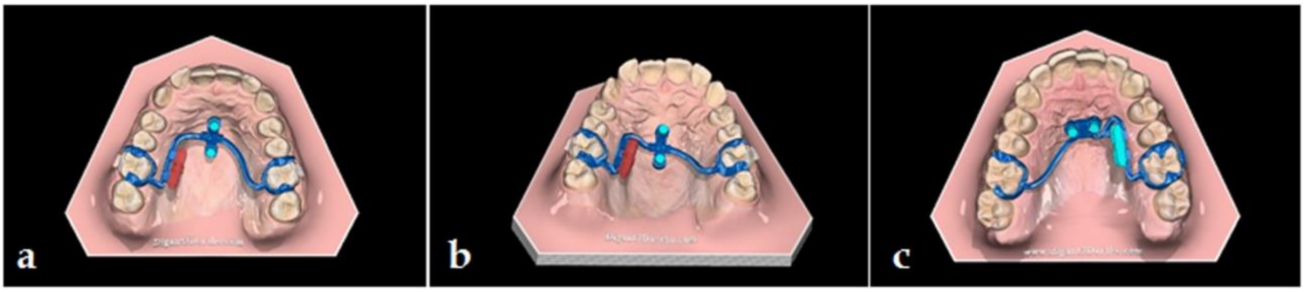

Figure 25 3D digital appliance design: a, b: TADs are placed median; c: TADs are placed paramedian. [Adapted from (26)]

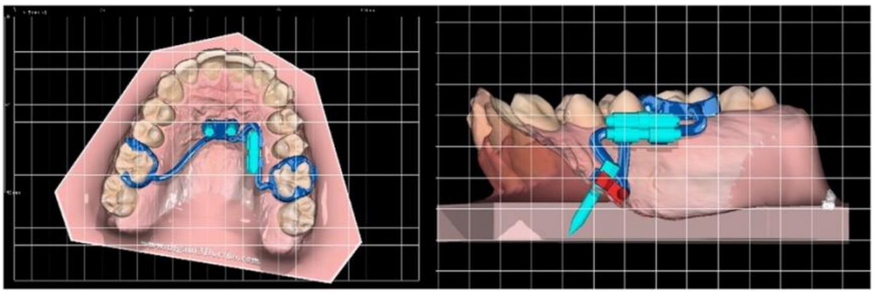

Figure 26 Hyrax orientation. (a) Parallel to arch form. (b) Parallel to the occlusal plane. [Adapted from (26)]

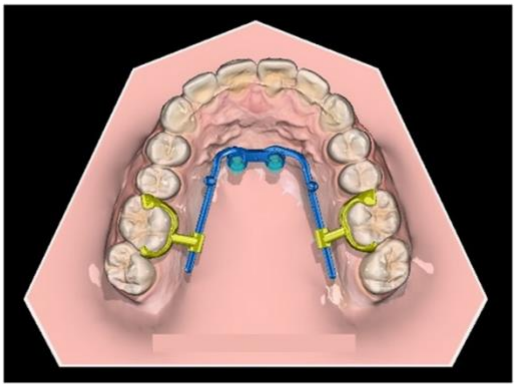

Figure 27 Slider designed for 3D metal printing. [Adapted from (26)]

4.8. Removable orthodontic appliances

When malocclusions are apparent or can be predicted early due to deciduous or mixed dentition, fixed appliances are not a treatment option. In this case, we can use removable functional appliances to modify growth, improve or remove bad habits, or eliminate unfavorable myofunctional forces. The most common malocclusion that can be treated with this kind of device is Class II division 1. These include Twin-block, Frankel II functional regulator, Activator, and Sander II orthodontic appliance. The manufacturing can be done in three ways: customized by dental technicians in the laboratory, partially premade appliances, or by complete production digitally and with 3D printing of individually tailored devices (27).

Various software can be used to design this appliance, including Exocad, Meshmixer, Blender, Blue Sky Plan, OnyxCeph, Ortho Analyzer, Rhino 3D, and many more. In the software, we can choose between diverse stocked parts from which the final device can be assembled. Each part can be adjusted and calibrated to achieve desired clinical results. This way, we can also personalize the parts and accommodate them according to the patient's teeth and gingiva positioning (27).

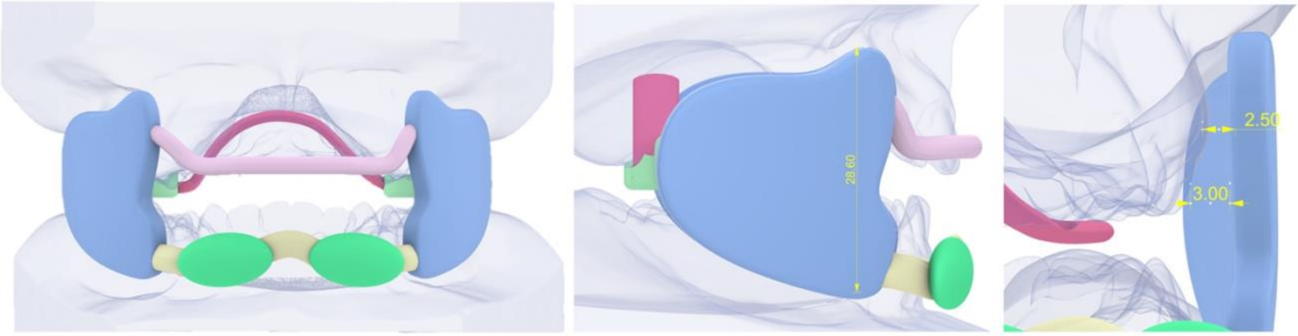

Figure 28 a) The digital design depicts the final version of a functional regulator type II (Fränkel/FR II), with different colors indicating the pre-designed parts that can be chosen to create the final appliance. b) These parts can be scaled and adapted using established analog manufacturing rules to achieve the best clinical outcome. c) Additionally, individual components of the FR II can be customized based on individual patient factors, such as the distance to the teeth, gingiva, or frenula. [Adapted from (27)]

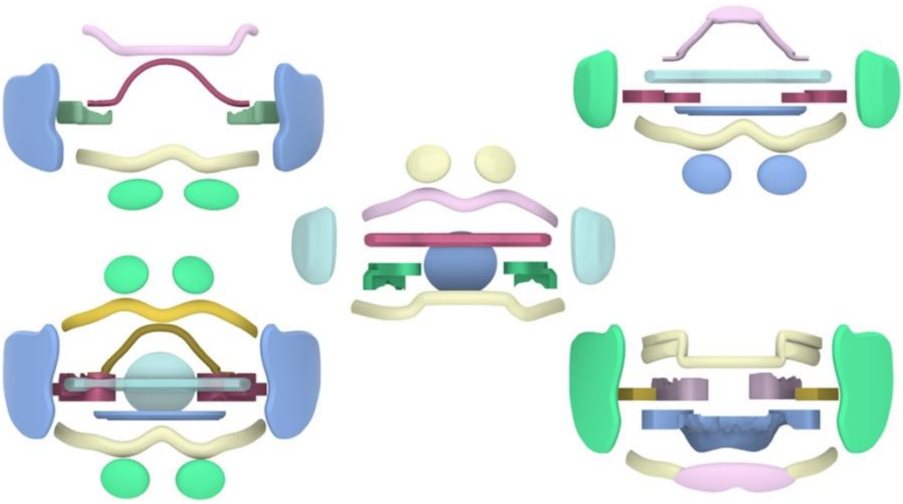

Figure 29 By utilizing a library of components, we can create numerous combinations of Fränkel type appliances. The availability of a configurator enables doctors to design appliances using preformed modules, which is an effective tool for communication with technicians and patients. [Adapted from (27)]

Figure 30 Illustration of all stages of a CAD/CAM FR II appliance. [Adapted from (27)]

Once the design is completed, it is saved in STL format for 3D printing. In this stage, choosing which biocompatible resin is the most suitable for our type of appliance is essential. Various resin materials are available on the market, including Dental LT Clear Resin from Formlabs, KeySplint Soft from Keystone Industries, NextDent Ortho Rigid from Vertex Dental, EnvisionTEC E-Ortholign from EnvisionTEC, and Tera HARZ TC 85 from Graphy. The material must possess a firm level of elasticity to overcome the undercuts when put in and out of the mouth while maintaining retention and withstanding the chewing forces and resistance to fractures (27).

The appliances can be fully printed in resin, or we can have so-called hybrids, which are a combination of digital and analog work with incorporation of wires and screws. With this, we can improve the anchorage of the appliance, which can present a challenge with this category of devices (27).

Figure 31 Customization and personalization of the printed appliances with the incorporation of premade screws and wires. [Adapted from (27)]

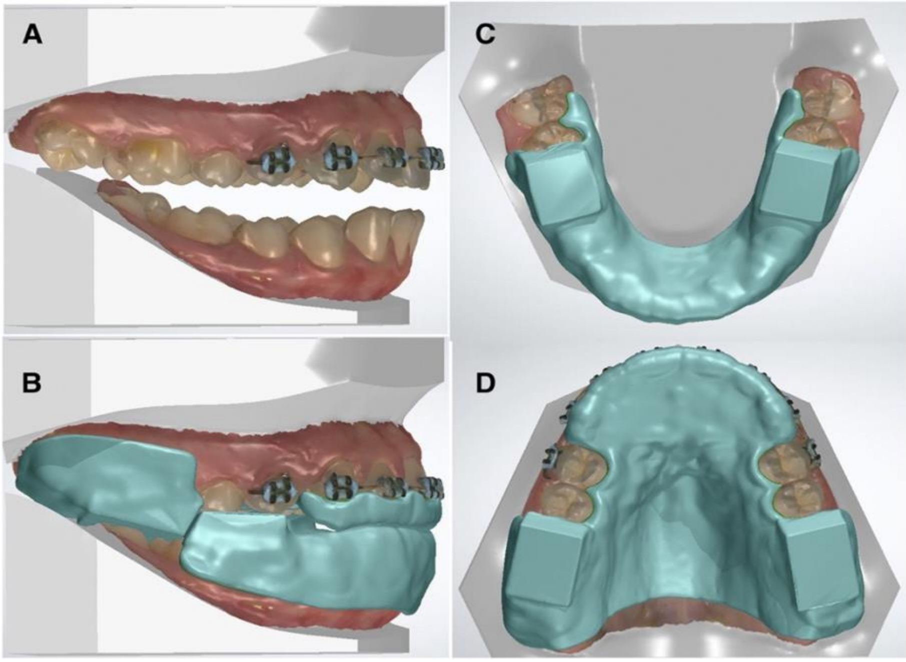

Figure 32 **A** Digital positioning of the jaws in Class I. **B** Virtual Twin-block design on the cast. **C** Virtual Twin-block design mandible occlusal view. **D** Virtual Twin-block design maxilla occlusal view. [Adapted from (28)]

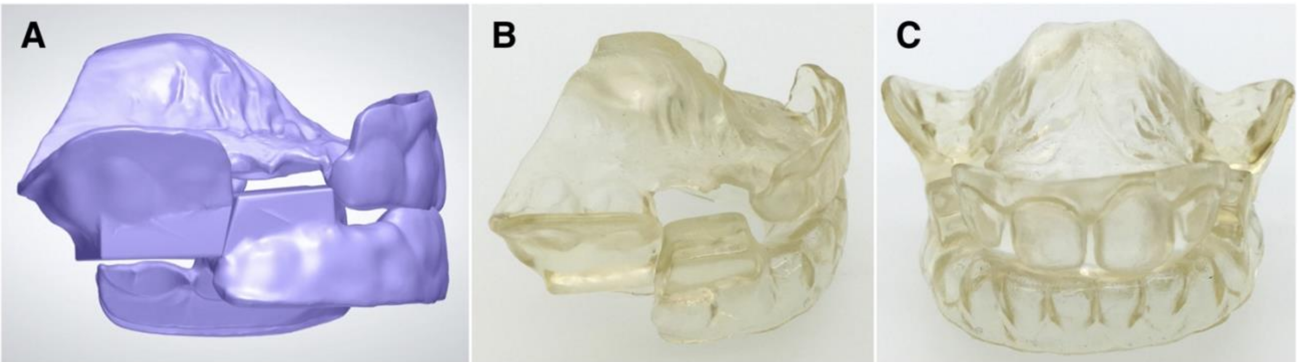

Figure 33 **A** Virtual Twin-block design. **B** 3D-printed Twin-block lateral view. **C** 3D-printed Twin-block anterior view. [Adapted from (28)]

5. DISCUSSION

Digital orthodontic treatment planning has revolutionized the field of orthodontics, providing practitioners with advanced tools and technologies to enhance precision, efficiency, and patient outcomes.

It comes as no surprise that digital technology has significantly impacted orthodontic research. For decades, the assessment of clinical treatment outcomes relied on comparing pre- and post-treatment two-dimensional cephalograms or the manual measurement of changes on plaster casts. The introduction of 3D superimposition techniques of study models as well as CBCT scans has enabled unprecedented insights into the effects of orthodontics, orthopedics, and orthognathic surgery, not only on the teeth and surrounding bones but also on the facial soft tissues and airways. It is almost certain this will become the standard for evaluating treatment outcomes shortly as radiation doses are reduced (15).

In today's busy world, people rely more on online shopping and accessing everything remotely. Dental Monitoring (Dental Monitoring SAS Paris, France) is taking this to orthodontics. Using the app, patients can take regular progress scans of their teeth and face with a smartphone and, through the company, communicate their progress to the managing orthodontist. In this way, patients are not required to attend the office physically until adjustments must be made. For the busy patient and family, this can make treatment less impeding on their time, and for the orthodontic office, it can free up significant chair time commonly used for progress checks. The technology can be paired very well with 3D setups, thus allowing patients to be alerted to attend the office once the wire has become passive. In terms of transparent aligner treatment, the technology can alert the patient and the orthodontists should there be a slight misfit on the aligner or if a tooth or group of teeth should not be tracked according to the desired plan. The application has gone further to offer live information for the patient on whether they are ready to progress to the next aligner. Fixed retainers, in their own right, can distort and move teeth. However, remote monitoring makes it possible to detect subtle changes early and alerts patients and orthodontists that a check of the retainers is in order (15).

5.1. Benefits

- With digitalization and digital tools, we lower the chance of errors by providing highly accurate measurements and visualization in treatment planning and execution.
- By showing them a 3D simulation of their treatment progress and outcomes, we help patients feel more satisfied, motivated, and compliant with treatment. Compared to traditional methods, we also increase their comfort level by taking a digital impression.
- The office time of the dentist and the patient's chair time is reduced due to faster and more precise diagnosis, treatment planning, and appliance fabrication.
- Each treatment is custom-made to the patient's specific needs, ensuring improved effectiveness and quicker orthodontic care.
    - Digital files make data easily accessible to collaborators, including orthodontic specialists, dental technicians, and maxillofacial surgeons, with just a click.

5.2. Challenges

- The equipment required for digitalizing a dental practice can be quite a financial burden, making it challenging for smaller practices to incorporate.
- To use this new technology, practitioners need to acquire additional knowledge; however, education and practice may require more time and adaptation.
- As with physical paper files and dental models, digital data must be protected and secured to maintain patient confidentiality.
- Despite the assistance of digital tools, the dentist should still thoroughly review the plan details and not overly depend on the digital tools, which are still prone to errors.
- It is essential to know which technology and software to use for each case since only some of the tools provide accurate and reliable results.

Digital technology is not without its dangers and negative sides. The rise of 3D printers and digital tools has led to the emergence of the do-it-yourself DIY orthodontic market –there are multiple recent reports of patients trying to perform orthodontic treatment using self-made appliances. Now, the companies offering direct delivery of aligners without requiring adequate assessment and diagnosis by orthodontists, poses apparent risks (15).

5.3. Future Directions

- The introduction of AI and Machine learning will further help with the prediction and personalization of treatment planning and make routine tasks human-free.
- The COVID-19 era has made people more open and comfortable with remote communication, leading to more remote monitoring and virtual consultations, further improving accessibility and convenience for patients.
- With further research and development, new materials can be utilized to fabricate more durable and practical orthodontic appliances.
- We will provide wide-ranging care solutions with enriched integration of digital orthodontics with other dental and medical fields.
- Future innovations will be based on improving patients' comfort and enhancing the overall treatment experience.

In the future, orthodontic offices will likely have desktop printers, and most appliances will be manufactured locally and custom-made per patient. Robotic wire bending will be commonplace, making wire bending robots available in the office. Aligner treatment will likely become more efficient and effective by creating direct printed-shaped memory plastics that replace braces. Smartphones will be able to perform accurate intraoral scans and patients will likely be able to obtain scans of the mouth using their own hand-held devices. It may be possible to have retainers replaced remotely. Very soon, it can be expected that more uncomplicated cases will be treated mainly by either DIY orthodontic providers or automated services with mail-order appliances. Orthodontic specialists will still be required, especially for managing more complicated malocclusions. However, more work will be done in front of computers, tablets, and mobile phones than in the clinic (15).

6. CONCLUSION

Digitalization in orthodontics is evolving every day and it is becoming a regular tool in dental offices.

Adopting digital tools should become a standard in educational institutions to facilitate a smoother transition into the dental and orthodontic digital journey. As written in the thesis, many different approaches and devices are available, to be able to choose the most appropriate one based on the case, knowledge and indication for these tools is required.

Digital planning begins with diagnostic procedures and digital model fabrication which are the foundation for developing further information and possibilities for orthodontic treatment. This progresses to digital design and printing of appliances.

Each step of the dental or orthodontic procedure always involves an error level. However, with the evolution of technology, these errors could be minimized or eliminated, which would give better results and speed up treatment outcomes.

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8. BIOGRAPHY

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