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Digitization in Clinical Orthodontics

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Abstract: Digital technology has substantially improved medical diagnosis, educational resources, therapeutic modalities, and surgical techniques over the past two decades. When computerised scheduling was introduced in dental and orthodontic offices in 1974, digital technology began to take hold. Every facet of orthodontic treatment has been impacted by digital technology. The aims of the study to review and highlight the contribution of contemporary digital orthodontic techniques in the success of orthodontic treatment.

Keywords*:* digital orthodontics, orthodontics, 3d imaging, CBCT, diagnosis, virtual planning

INTRODUCTION

Digital dentistry is the term used to describe the different modalities of dental treatment workflow that are mostly performed with the use of digital technologies.[1] Several digital methods have been incorporated to dental practice to replace conventional methods and techniques in order to enhance treatment planning and predictability of execution.[2] Nowadays, digital dentistry is considered a whole field of study within dentistry.[3] As with any other field of study, digital dentistry involves a learning curve to be mastered and used in the clinical routine.[4] Ultimately, the dental professional is responsible for using existingdigital tools appropriately for patient treatment.[5] In other words, the basic theories of dentistry are still the same and should be very well known by the professional, who will be able to use these new digital tools to enhance predictability in executing the treatment plan.[6]

The construct of "digital" did not stop with machine development but acquired a broader meaning.[7] It has evolved to encompass everything linked to digital or computer technology, as well as to describe any computer-mediated equivalent of an object or entity that exists in the palpable world. Daily uses of this concept are digital shopping carts and digital books, among others. Not only ordinary objects but also professions, expertise fields, and whole organizations acquire the digital software) for their activities. Examples of this are the many references to digital dentistry or the thriving European Academy of Digital Dentistry that

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quickly became one of the most respected and widespread scientific societies in the dental field.[6,7]

Orthodontics and dentofacial orthopedics are one of the most complex branches of dentistry that requires a careful interpretation of a large amount of information to attain a correct diagnosis and treatment planning. Similar to a wax setup, the digital setup is a tool that helps with treatment planning and it is up to the creator of the setup to respect the biologic limitations of tooth movement and mimic realistic biomechanics.[8 -13]

Orthodontics, like the other dentistry disciplines, has recently benefited from the influx of technological innovations. These innovations have principally involved the means and procedures of diagnosis, with new developments being introduced in the field of photography, tomography, optical and laser scanning **.[9]** Several orthodontic systems implement these new technologies, providing the orthodontist with a comprehensive orthodontic treatment package consisting of digital diagnostics, 3-dimensional (3D) digital planning, and computer-designed customized brackets and arch wires.[10-21]

Digital technology has already become indispensable to modern dentistry, and the use of 3D technology in orthodontics has increased in recent years. The digital technology has contributed to improve and simplify diagnosis, treatment planning and execution in Orthodontics. [13,15]

The developments and introduction of intraoral and facial scanners, digital radiology, and cone-beam computed tomography (CBCT) have transformed diagnosis and treatment planning from a traditional two-dimensional (2D) approach into an advanced three-dimensional (3D) technique. A more recent breakthrough is the advancement of computer-aided design and computer-aided manufacturing

(CAD/CAM) and 3D printing technology that is utilized to design and create “personalized” orthodontic appliances. Among CAD/CAM system (Computer-Aided Design Computer - Aided Manufacturing) applications in Orthodontics, it highlights the installation and removal of fixed appliance, clear aligners, customized appliances, and retainers fabricated in digital environment. This approach has several advantages for practitioner and patient, as it enhances

appliances precision, directly interferes in treatment time and predictability. Such systems not only shorten treatment time, making cases more predictable and less labor-intensive, but allow doctors and patients to preview virtual results before

treatment begins, thus facilitating communication, understanding, cooperation, and case acceptance. Even with all the benefits arising from the digital workflow, few

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orthodontists have adopted this technique in their clinical practice, most due to high cost and lack of technical preparation for proper execution [7-13].

Two-dimensional imaging techniques such as panoramic, cephalometric radiography and dental photographs have been used by orthodontists for years for basic orthodontic diagnosis, treatment planning and case follow-up.[13] However, it

is not possible to solve some complex cases with these two-dimensional

methods. For this reason, computed tomography (CT) was the only medical option used in cases such as temporomandibular joint pathologies and impacted teeth.

However, the use of CT also has some disadvantages. [13-15] The high radiation dose emitted by CT made physicians very cautious when the average age of the patient population in need of orthodontic treatment was considered. Because the radiation dose emitted by CT for a simple impacted tooth localization is quite high. Newly developing technologies and alternative options with digital transformation have contributed to the solution of these problems. [1-13] Some of the technologies used in orthodontics with digital transformation are as follows;

1. Cone Beam Computed Tomography (CBCT): CBCT has

become a great alternative to CT, especially with its relatively low radiation dose and low cost.

2. Digital Image Collection Methods a. Intraoral

Scanners; b. Extraoral Scanners.

3. **Three-Dimensional Printers**

4. **Aligners**: Clear aligner treatment with Invisalign, introduced by Align Technology, pioneered the use of a virtual model, creating a virtual treatment plan, and producing devices from digital models [7,13,14,15].

Advantages of digital orthodontics

1- Accurate tooth positioning, less human error during indirect bracket bonding, and the possibility of maintaining the pre-treatment arch form. [11,13]

2- Secondary advantages can be faster treatment, with less secondary effects that are time-dependent and more accurate and precise outcomes. [12-19]

Disadvantages

• High initial and maintenance cost.

• Taking the bite registration can be an issue with certain types of malocclusion

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like posterior cross bite or open bite

Aims of the study

To review and highlight the contribution of contemporary digital orthodontic techniques in the success of orthodontic treatment.

Digital Diagnosis

Orthodontics and dentofacial orthopedics is one of the most complex branches of dentistry that requires a careful interpretation of a large amount of information to attain a correct diagnosis and treatment planning. Similar to a wax setup, the digital setup is a tool that helps with treatment planning and it is up to the creator of the setup to respect the biologic limitations of tooth movement and mimic realistic biomechanics .[8-14,19-21] Barretoa et al. reported that the creation of a digital setup is much faster than creating a wax setup due to the lab work required when working with plaster.**[22]** Working with digital setups offers many advantages such as relatively time saving, the ability to superimpose the setup with the original models, determining the precise amount of movement for each tooth, and it can be instantly stored and shared with others easily.[23]

Digital Study Models

Plaster study models were the "gold standard" in orthodontic diagnosis and treatment planning **.[13,24]** Later advances brought about more dimensionally stable impression materials than wax and alginate, such as elastic polyether and polyvinyl siloxane.[25] Study models provide a three-dimensional view of a patient's occlusion and are more amenable to routine measurements like tooth size, arch length, arch width, overjet, overbite, midline discrepancy, curve of Spee, etc.[23] However, it has disadvantages like lack of tactile input, time required to learn how to utilize the system so if it does not done accurately it will need extra time to repeat it, scarcity of digital model supplier companies, questions surrounding the accuracy of digital models and additional costs.[13,26]

On the other hand, the concept of three dimensional (3D) virtual orthodontic models seems very favorable in eliminating the problems of conventional plaster models, and simplifying the practice management and communication between different specialties. Virtual study models made their first appearance on the orthodontic market in 1999.[27] The startup software for OrthoCAD is free of charge, OrthoCAD's 3-D browser software allows the clinician five simultaneous views of the models. This enables the models to be viewed from multiple perspectives at the same time, also Ortho CAD also features a cross-sectioning tool that can slice the digital models in any vertical or horizontal plane to check symmetry, overjet, overbite or to measure any location.[13-15,25] **(Fig. 1 A-F)**

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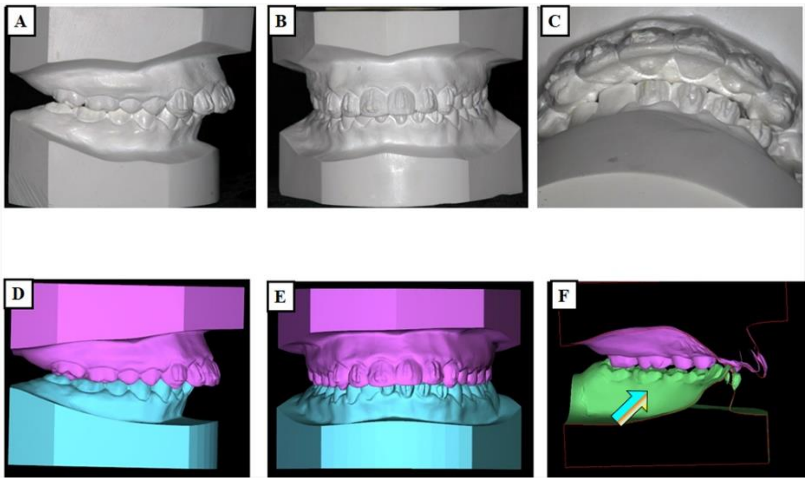

Fig. 1A–F: ***A–C:*** **Plaster models taken at the beginning of treatment, used for documentation and for analyses of space conditions, occlusal relationships, and dental malpositions.** ***D–F:*** **Three-dimensionally digitized plaster models, allowing for a more detailed assessment of occlusal quality both before and after treatment.**

Shape Ortho System is a recently introduced 3-D representation of a patient's dentition on the computer screen. The system utilizes a propertied laser scanner (R700) that projects a laser line onto the surface of the model or impression, a 3-axis motion system and two high resolution charge-coupled-device cameras, one on either side of the laser that observes the profile of the line as it falls on the object.[27] The two-camera system reduces scanning time because less reorientation of the model is required to capture surface details that would be missed by a single camera due to shadowing**.[15,28]**

They have typically been made of stone or plaster. Digital models have been invented to avoid several disadvantages of traditional models in terms of lifetime, portability, and storage and retrieval, offering various advantages namely, no laboratory procedure needed, the ability to create multiple diagnostic setups, no physical storage space required, fast and efficient retrieval at any location, no risk of physical damage, can be used to create indirect bracket bonding setups, precision in measurements such as tooth size, arch length and width, space analysis etc., and can be easily shared with other dental practitioners via email to facilitate interdisciplinary treatment planning, Ideal marketing tool because it enables virtual treatment objective (VTO) communication with patient, visualization of treatment outcome, and help the patient better understand the treatment process.[14,29,30]

These can be obtained directly by intraoral scan or indirectly by scanning an impression or plaster model. Software enables free toggling in all planes of space and even opened to allow upper and lower models to be viewed and manipulated separately .[29,30]

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One of the commonest scanners is the iTero Element 5D by Align Technology that provides Invisalign result simulator feature which gives full scan of the mouth in 1 min and the patient can see an example of a possible result after orthodontic treatment.[13-17,27-29] **(Fig. 2 A-D)**

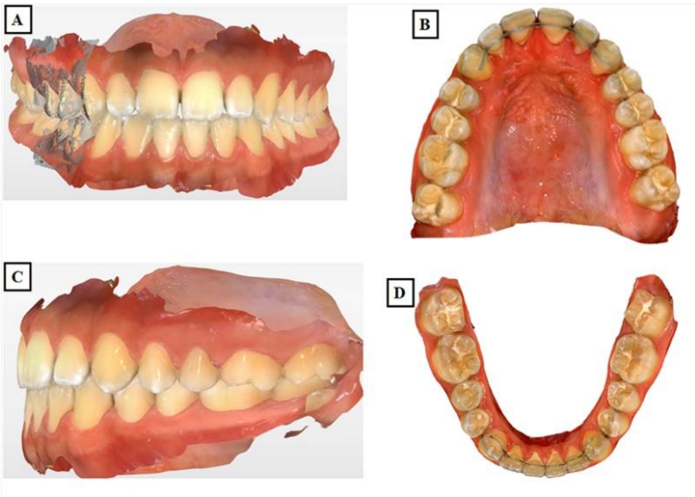

Fig. 2A–D: Intraoral scans acquired for detailed analysis and digital documentation of the dental and jaw conditions.

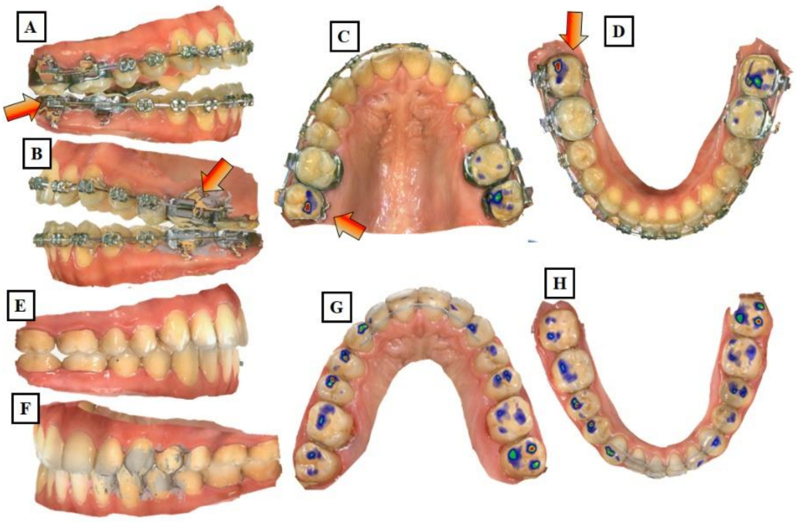

Fig. 3A–H: Intraoral scans before and after treatment, allowing for a detailed analysis of occlusion. *A–D:* Representation of the initial situation with an anterior open bite and occlusal contacts limited to the second molars (red arrows). *E–H:* Scans taken after completion of treatment; the blue markings illustrate the achieved occlusal quality in comparison to the initial condition.

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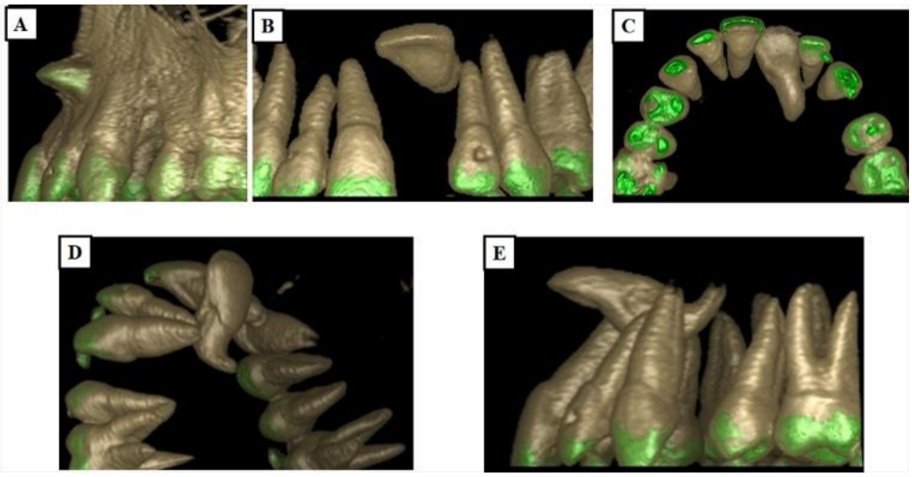
DIGITAL OCCLUSION SCAN

The **T-Scan System** is an occlusal analysis system designed to measure and record relative biting forces over time, being successfully used in orthodontics[33], prosthodontics [33,34,35], implant dentistry and patients presenting bruxism or other craniomandibulardisfunctions. The latest model, the 3rd generation system, includes intraoral sensors, scanning electronics and intuitive software. The mouth-shaped sensor fits into a sensor support that inserts into the sensor handle connected to the USB port of a PC and is easily movable among operatories.[32,33] The **T-Scan** software records and stores occlusal data in a patient database, while providing occlusal analysis features that allow dental professionals to determine the first and last contact, the balance of occlusal contacts present at any given moment, as well as to view multiple scans to compare bites. Graphic displays on computer's monitor are also an aid to patient education [15,35,36]. **(Fig. 3 A-H)**



DIGITALLY-BASED SURGICAL GUIDES

Surgical tooth extraction is a common procedure in dentistry. However, in practice, numerous extraction cases show a high level of difficulty, usually related to an inadequate visualization, improper instrumentation, or other factors related to the targeted tooth. With the aid of 3D imaging, computer planning and 3D printing, a new surgical complications in dental surgical extraction procedures.[37] Due to the precision of this technology, the accuracy specifically tailored for each patient with one or multiple teeth that need surgical extraction.[38,39] access to the surgical field. Visibility is not important, as the stent is capable of providing direct access to the target area. Surgical extraction using the surgical guide could minimize postoperative bleeding, tissue laceration, and pain. It has recently been used with success in maxillofacial surgery in mesiodens removal, in children and adolescents [13-17,21,38-40].

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Digital Photographs

The digital single lens reflex cameras were verified for use in intra and extra-oral photography and proved to produce perfect images when used with the recommended macro-lens and macro-flash techniques. Digital photography was introduced to evaluate facial harmony. It allows clinicians to establish a more proportional focus on all three structures of the triad to assess patient's deformity **.[13-18]**

CBCT

Cone-beam computed tomography (CBCT) is a radiographic technique introduced to the United States dental market in 2001. CBCT technology uses a cone-shaped source of ionizing radiation and a two-dimensional detector.[39] CBCT has concerned significant attention from practitioners who seek to enhance diagnosis and treatment for their patients. However, risks and limitations need to be explored and weighed against the benefits of CBCT in each case.[21,39]

Theoretically, any amount of ionizing radiation, no matter how small, has the potential to cause a harmful effect. Radiation is a carcinogen, and current radiation protection protocols are based upon the linear non-threshold (LNT) assumption that even very low doses of radiation can cause cancer.[21,40] The problem in orthodontics is that most patients who undergo orthodontic therapy are children and adolescents, being more radio-sensitive and susceptible to the untoward effects of ionizing radiation than adults. Because the dose received is strongly related to the field size, a small field of view (FOV) can be selected for the region of interest that triggers the interest in CBCT acquisition **.** In order to improve the use of CBCT, the FOV should be justifiable, patient-specific, and indication-oriented **.[17-21]**

The effective dose of a digital panoramic radiograph has the range of 6–38 micro-Sieverts and the effective dose of a cephalometric radiograph has the range of 2–10 Sv, while the range of effective doses of CBCT is very large and has been reported to be 5.3–1025 Sv, depending o n the size of FOV, specific technique factors, and the machine itself.[21,41]

Further to the exposure to ionizing radiation, CBCT comes with other restrictions and concerns. For example, CBCT scanners have higher cost and limited accessibility when compared to conventional radiographic imaging techniques. In addition, CBCT images are adequate for visualization of teeth and bone, but are unable to represent the internal structure of soft tissues or soft tissue lesions with high accuracy **.[14,40]** One of the artifacts that happen with CBCT are metal artifacts. In orthodontics, these artifacts can be noted on the images around orthodontic brackets and bands (scattering), display noise, cupping artifacts and motion artifacts, especially in young orthodontic patients who are more likely to move during long CBCT scans.[15,42]

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The great advantage of CBCT is that it provides images of various dental, oral, and maxillofacial structures in multiple orthogonal images (i.e., coronal, sagittal, and axial sections) **.[13-21]** The use of CBCT must be justified if conventional imaging techniques such as panoramic and cephalometric radiographs fail to provide correct diagnosis or when CBCT has a positive effect on treatment options or treatment optimization.[21] For example, the American Dental Association recommended that CBCT be decided only when there is an expected diagnostic benefit for the patient or significant improvement in the clinical outcome . The British Orthodontic Society guidelines are comparable, and did not recommend CBCT imaging for all orthodontic patients **.[43]**

CBCT provides information on impactions and ectopic teeth eruption, the stage of dental development, position and size of the tooth or follicle, evaluation and detection of any supernumerary teeth (Fig. 4 A-E). CBCT can be used in craniofacial orthodontics in which effects of maxillary expansion, evaluation of the clefts, and the skeletal and soft tissues can be evaluated in all dimensions (Fig. 5 A-D). If temporary anchorage devices such as mini-implants or mini-plates are planned before or during orthodontic treatment, CBCT can help the orthodontist in evaluating the planned site for insertion or the status of the temporary anchorage device after the insertion. [44] One of the great features of CBCT is its ability to construct different views, such as a panoramic view of the teeth and adjacent structures and another cephalometric view. Therefore, if a large volume CBCT is made, these views can be generally made without taking additional 2D panoramic and cephalometric radiographs.[13-17,45]

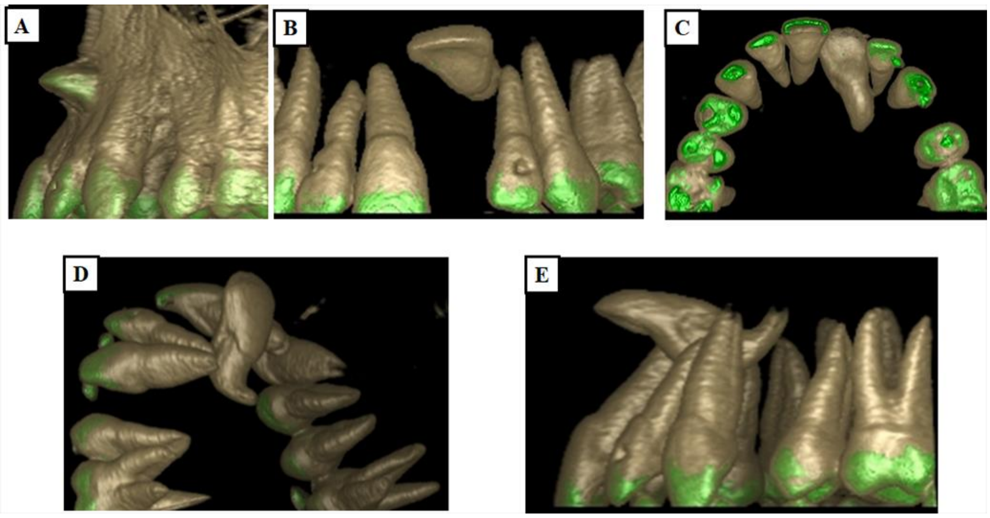

Fig. 4A–E: The CBCT scan reveals a retained maxillary anterior tooth. Detailed analysis of the imaging data allowed for the identification of both the severity of the impaction and morphological deformities of the tooth, leading to the determination of a contraindication for surgical exposure and orthodontic alignment.

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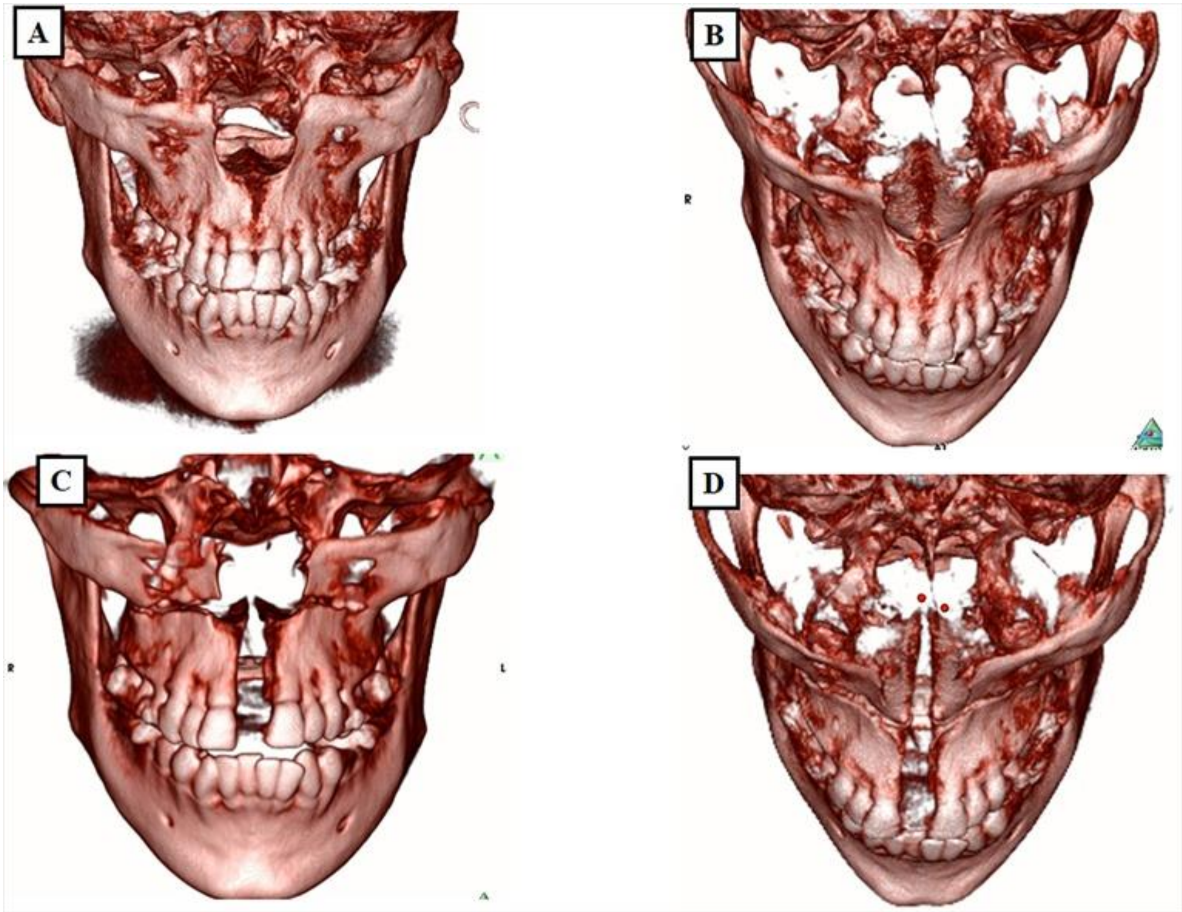

Fig. 5A–D: CBCT images of an adult patient following surgically assisted rapid palatal expansion. *A, B:* Depiction of the anatomical situation prior to expansion. *C, D:* Post-expansion images; the maxilla was separated in both the vertical (*C*) and sagittal (*D*) dimensions, demonstrating the successful division of the bony structures.

CBCT provide accurate localization of impacted teeth. It can supplement panoramic radiographs when impacted canine inclination exceeds 30 degree, the root apex of canine is not visible clearly or when the root resorption of adjacent lateral incisor is suspected.[46] [46]Precise localization of impacted teeth can affect the diagnosis and treatment planning of the case but its role in reducing the treatment time and facilitation of surgical exposure can't be confirmed.17 CBCT improves the clinician's confidence about their treatment decisions. Also clinicians have rated higher proportion of teeth with root resorption on CBCT images. [47] teeth (Fig. 6 A-E)

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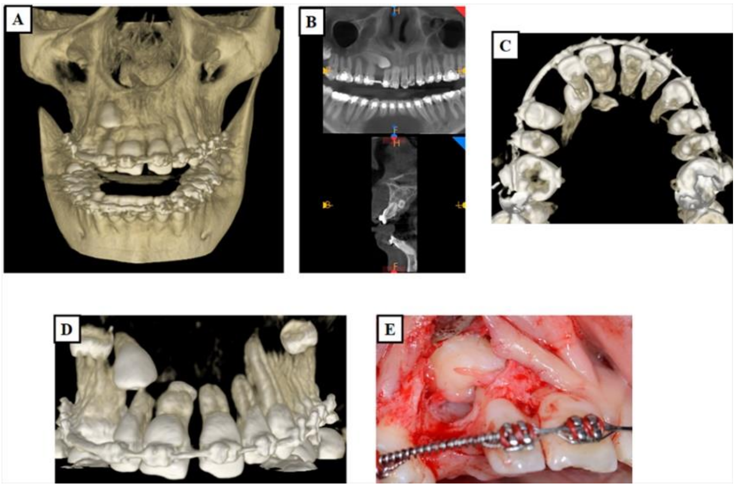

Fig. 6A–E: CBCT images of a displaced and impacted canine (tooth 13). The high-resolution imaging allowed for precise assessment of the unfavorable position of the impacted canine, located in close proximity to tooth 12, where it caused external root resorption. Based on this detailed information, a targeted surgical exposure and the application of controlled orthodontic forces were planned and executed, effectively minimizing the risk of further damage to adjacent teeth.

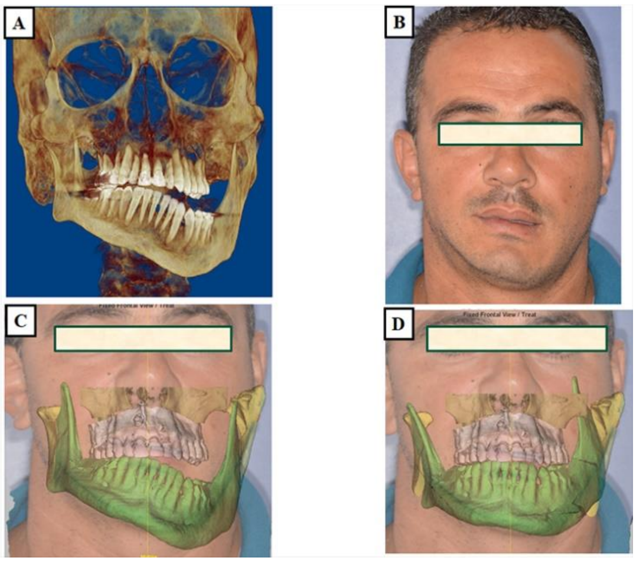

Fig. 7A–D: CBCT and extraoral images used for the analysis and treatment planning of a patient with right-sided laterognathia. *A:* The CBCT scan confirms the skeletal asymmetry. *B:* The facial asymmetry is clearly visible in the extraoral photograph. *C, D:* A virtual simulation of the surgical correction was performed on both the hard and soft tissues as part of the preoperative planning.

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The use of CBCT to predict or evaluate the outcome of treatment for dentofacial abnormality cases like syndromes, facial asymmetry or orthognathic surgery is the most researched application. Planning of realistic surgical movements, virtual stimulation and prediction of soft-tissue adaptation can be done by collaborating CBCT with specific surgical planning software and CBCT can be used to asses the maxillomandibular anatomy, size, volume and location of the bony defect, canine displacement, presence of supernumerary teeth. [48] (Fig. 7 A-C) CBCT can also be helpful in evaluating the post-surgical outcome like bone volume post-alveolar grafting and morphology of alveolar bone. [49] CBCT in cleft patients provide better insights into the problem and is an accepted indication for the problem.

CBCT evaluates both the right and left TMJs in a single 360 degree rotation compared to tomography which usually requires four cuts in frontal and lateral plane. [50]This cumulatively reduces the radiation exposure. CBCT images provide superior view of condylar morphology, erosions and structural deformity (Fig. 8 A-E)**.**25Nevertheless, it is pertinent to understand that CBCT is not recommended in TMJ problems like myofacial pain dysfunction syndrome (MPDS) or internal disk derangements. MRI is usually recommended in such cases. [51-56]

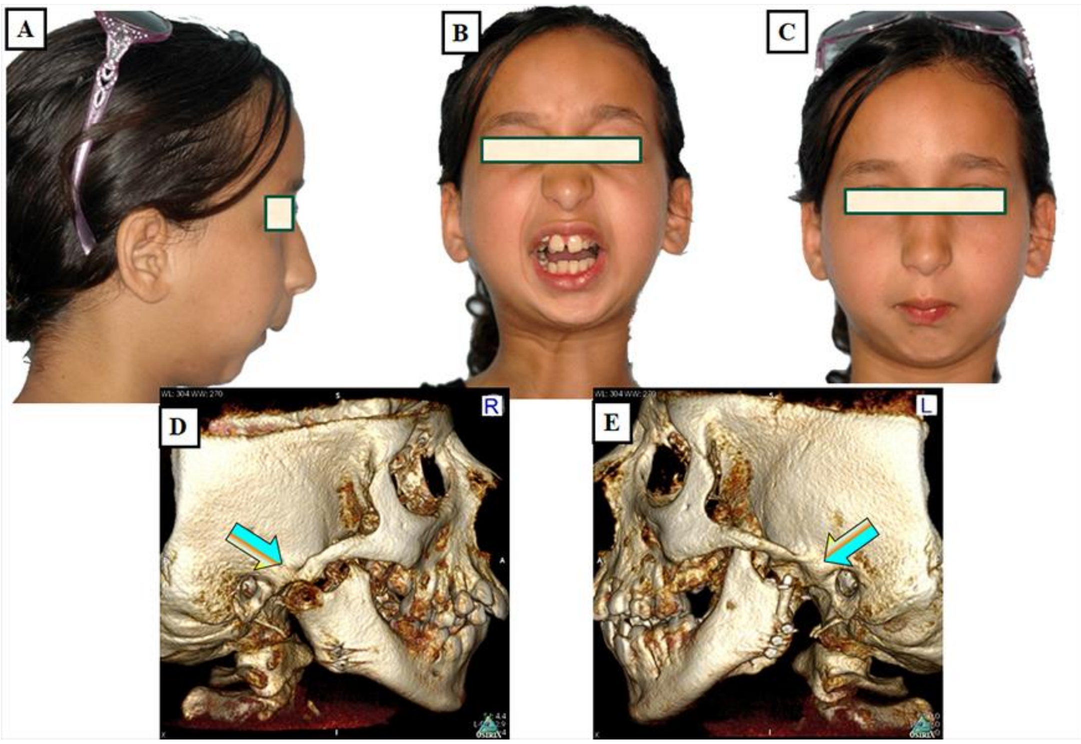

Fig. 8A–D: Female trauma patient with a temporomandibular joint fracture. A marked facial deformity was observed, accompanied by impaired jaw function. The CBCT images provide a detailed visualization of the damaged condyles (blue arrows) and support the diagnostic assessment of the extent of the fracture.

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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 (Fig. 9). 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:

1-Image filtering plus edge-based approach

2-Model-based approaches

3-Machine learning approaches

4-Hybrid approaches

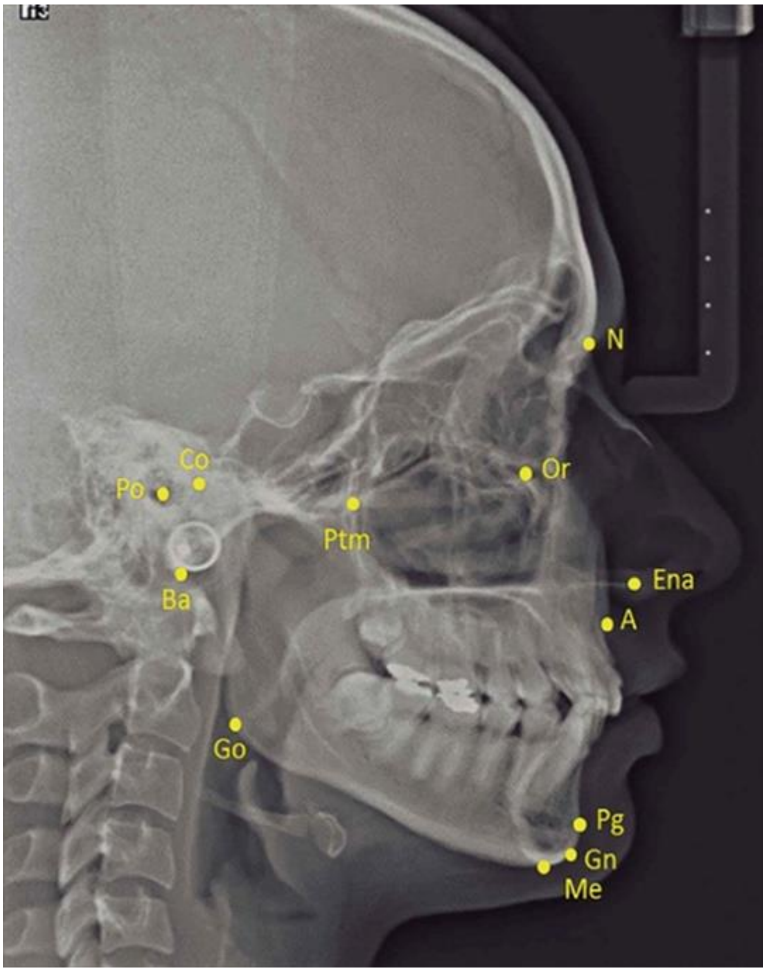

Fig. 9: Digital cephalometric radiograph used for skeletal and dental analysis, as well as for assessing the growth status in growing patients.

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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 . [57]

The superimposition, picture quality, and magnification of structures influence the accuracy and reliability of the measurements .[18-21,58]

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 .[59]

Goals in digital orthodotics

A major goal of orthodontics is establishment and maintenance of an appropriate arch form for each patient, and the treatment goals should be defined during dignosis and treatment plan steps.[43] According to the reserch, the mandibular arch form should not be modified to a major extent, and that teeth should be positioned within the zone of equilibrium between the internal and external forces.[60]Important outlines to be considered:

1- The use of non-customized orthodontics with preformed arch wires does not allow for maintenance of the arch form, especially using the prefabricated NiTi wires. A solution to this problem can be the use of setup-driven, manufactured orthodontic appliances where the initial arch shape is incorporated into the design of the brackets and wires.[13-17]

2.Goal-driven orthodontics is achieved most effectively by a proactive process of design and manufacturing of orthodontic appliances where the target tooth positions are planned on a dental setup. The setup includes both intra-arch and inter-arch tooth positioning. In other words, the position of each individual tooth in relation to its neighbors is defined in the three-dimensional space; then it is refined based on the desired occlusion.[43]

3.- The amount of tooth displacement, rotation and overall expansion can be quantified and adjusted during appliance fabrication **.[13-21,60]**

4. The expression of torque or inclination of the upper incisors and canines. This is due to the use of undersized wires in slots that often are oversizedand. Custimized digital orthodontics can provide specific slot dimensions for optimal torque and inclination achievements.[40]

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indirect bonding

One of the imperative phases of orthodontic treatment is the finishing and detailing phase, which involve a series of steps that essentially begins with ideal bracket positioning.50 years ago Lawrence F. Andrew advocated six keys of normal occlusion 10 and based his straight wire appliance (SWA) to achieve minimal wire bending never the less controlling tooth movement and alignment in three spatial planes through ideal bracket positioning. ideal bracket positioning is the ultimate treatment outcome providing shortest treatment time together with minimal bracket repositioning, eliminating wire bending as well and definitely reducing relapse chances. Brackets can be positioned clinically either directly with an instrument or indirectly with a transfer tray. Indirect bonding (IDB) was first proposed in 1972 Silverman and Cohen [61] described the indirect bonding technique for the first time and identified Few years later the claimed advantages of indirect bonding were questioned in a roundtable discussion. Gorelick and co-workers [62] responded rationally that having the teeth in your hand looking freely from any direction would facilitate ideal bracket positioning. Several publications were conducted to evaluate (IDB) accuracy, chair time and bond failure. Previous studies of Aguirre [63], Koo et al [64] were consistent with Sabbagh [65], findings in systematic review that indirect bonding as a technique allowed achieving planned bracket positions with high overall accuracy. However these conclusion were inconsistent with Hodge etal [66], that stated that there were no significant difference between mean bracket placement errors of both techniques . Conversely in, a systematic review by Li and his colleagues [67] presented weak evidence that the direct and indirect bonding techniques had no significant difference in bracket placement accuracy. Upon studying bond strength, according to several studies, indirect bonding had a similar or lower bond failure rate than conventional direct bonding [68,69].Also, claims of reduced chair time[63,70] were inspected, to truly conclude that chair time is reduced, but on the expense of extra laboratory working time with additional equipment. This overly complex chairside and laboratory phase contributed to minimal percentage of orthodontists that employ indirect bonding as part of their daily practice, with prevalence of only 18% among clinicians. Other advantages included less physical stress and improved productivity of orthodontist as all bracket placement decisions have been previously made in the laboratory. [64]

The latest advances in digital technology, such as intraoral scanning, 3D printing, and virtual setups, made indirect bonding a much easier and more predictable procedure that was worthwhile for clinicians to explore. STL files is utilized to produce the models needed for indirect bonding techniques. After digital bonding through orthodontic modules provided by several softwares as OrthoAnalyzer i , OrthoCAD ii ,SureSmile iii (Orametrix, Inc., Richardson TX),[61,62] a 3D-printed transfer tray or vacuum formed tray on 3d printed bonded models is constructed and delivered to patient mouth .[64] As reported by various studies computer aided indirect bonding has less total treatment time assuming higher

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bracket positioning accuracy and less chair time [73] contradicting some studies that stated no significant difference interims of accuracy .[74,75]Despite the latter studies, the accuracy of computer aided indirect bonding remains questionable.

Insignia system

Orthodontics, like the other dentistry disciplines, has recently benefited from the influx of technological revolution. Innovative systems able to construct orthodontic appliances customized for the patients have been introduced to the market.[40] Technologic advances in photography, digital scanning, and cone beam computed tomography (CBCT) have greatly improved the diagnostic and treatment planning procedures in orthodontics. Correspondingly, the application of computer-aided design and manufacturing technologies has allowed manufacturers to produce orthodontic appliances tailored to the specific tooth shape of the individual patient; i.e, customized orthodontic appliances. [43]

The Insignia System (Ormco, Glendora, Calif.) is one of the most advanced computerized systems for obtaining personalized appliances for patients.[43] By using this system, the orthodontist takes impressions of the dentition with a polyvinyl siloxane impression material (PVS) and sends them to the manufacturer. Impressions are digitalized and uploaded into the software program, and the orthodontist can upload more information, including intra- and extraoral photos and x-rays. The system enables optimization of treatment results with computer-aided smile design .[40,75] Theoretically, individualized orthodontic treatment systems offer several advantages for both the patient and orthodontist, including better treatment results, shorter treatment duration, and less chair time**.[76]**

With fixed appliances, tooth movement occurs as a result of the engagement of the wire in the bracket slot. A system of forces and moments is generated and is transmitted to the tooth and its surrounding periodontal ligament. There are three customization approaches to generate a theoretical ideal force system and produce the desired tooth displacement.[43]

1. Individualized arch wire
2. Individualized bracket slot/bracket base
3. A combination of the first two approaches

Because of individual variations in the contours of the teeth, no appliance prescription can be optimal for all patients, and compensatory bends in finishing archwires often are necessary. Custom brackets for the facial surface of teeth offer the prospect of eliminating almost all archwire bending. The Insignia system uses custom brackets on each tooth, focusing on eliminating wire bending to make the appliance more time-efficient for the practitioner and patient.[40]

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The first phase involves the collection of diagnostic information. In addition to extra- and intraoral photographs of the patient, it is necessary to gather very precise information regarding the patient's occlusion and the coronal morphology of their teeth. Some systems require that this information be acquired by means of precision impressions, while others rely on intra-oral scans of the teeth or volumetric tomography of the dental arches . For custom-designed orthodontics, the approach is to send precise polyvinyl siloxane impressions as well as photographic and radiographic information to the manufacturer. An accurate scanning of the plaster casts or CT scanning of the impressions is performed by the technicians, thus producing a digital model with 3D representation of the dental arches.[41-45] Alternatively, a 3-D scan of the dentition is taken to produce an STL file (now the most frequent input). Whatever the source, the virtual teeth need to be accurate to least 50-micron resolution to produce a virtual setup of the desired final tooth positions and archwire shapes are derived.[15,40]

To make adjustments to the proposed initial occlusal setup and archwire shape via the online interface **[40,43]**:

1. 3D control of tooth placement (torque, tip, in/out, intrusion, and extrusion) .

2. Control of the arch form within the patient-specific biologic limits based on the buccal and lingual limits of the alveolar bone.

3. Alteration of the smile arc . 4. Alteration of the dental contacts in the final centric occlusion.

The second phase of these systems involves the use of the developed data on the patient's teeth and occlusion for digital replication of the dental arcades using reverse engineering processes. This consents acquisition of digital models of the arches, in which each tooth is defined as a CAD-CAM object, whose position can therefore be altered in three-dimensional space for virtual simulation of an ideal occlusion.[40-45]

The third phase in this system involves the construction of orthodontic appliances customized for the patient. This customization can be performed on three different components of the appliance; the bracket can be individualized, compensation bends can be added to the orthodontic archwires, and personalized jigs. The patient-specific appliances (brackets, archwire, and precision positioning devices) are not fabricated until the doctor has reviewed and accepted the virtual treatment planning. This digital information then is used to precisely cut each bracket by (CAD/CAM) technology, so that the slot for each bracket has the appropriate thickness, inclination, and torque needed for ideal positioning of that tooth, and archwires with an arch form established for that patient are supplied. The result is "the ultimate straight-wire appliance," with wire bending reduced to a minimum if not totally avoided.[15,17,41 -43]

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Unlike many other systems, in which personalization entails the modification of the thickness of the composite used to adhere the bracket base to the tooth crown, in this system the brackets themselves are milled to the correct specifications . Insignia self-ligating (SL) brackets are a customized version of Damon Q SL brackets (Ormco), which are individualized by varying the thickness and angulations of the metallic bases. When esthetic brackets are selected, no milling can be performed; therefore, customization is carried out by prescription selection, adjustments to the positioning jigs, and customized archwire design . An indirect bonding tray composed of bracket transfer jigs which precisely milled from sponge material that created to fitthe occlusal surface of the tooth to transfer the virtual position of the bracket to the patient's mouth. Orthodontic treatment proceeds by arch wire progression.[40] The Insignia system also permits personalization of metallic archwires with first-order compensation bends; this can be done to all wires required to complete the treatment, whether made of CuNiTi, stainless steel or TMA **.[43]**

Because the specifications for each bracket can be maintained in computer memory, it is possible to obtain a replacement bracket and bonding template within 2 to 3 weeks. Rebonding a loose bracket is done most efficiently by using the original bonding template, which should be kept with the patient's records for this possible reuse. In its absence, if alignment of the teeth has been completed, the archwire can be used to position the bracket. Even at that point, the custom brackets and archwires do not make the dental arches fit together. That relies on interarch relationships, which usually are provided by interarch elastics and are mostly under the control of the patient.[40] A disadvantage of this system includes the potential for error in bracket positioning, either virtually or during transfer to the mouth.[15-21.43]

Clear Aligner Therapy (Invisalign)

With the recent increase in adults seeking orthodontic treatment, there has been a corresponding increase in demand for appliances that are both more aesthetic and more comfortable than conventional fixed appliances.

Invisalign aligners consist of a series of clear, removable, plastic appliances that the patient wears sequentially to achieve the final result.[77]

The Invisalign system uses a computer-based online software to plan the treatment ahead of time and then orthodontist can share the expected final results with the patients (Fig. 10 A-I). Invisalign aligners were introduced to offer not only the advantage of better esthetics but also the convenience of removal during consumption of food and beverage, less pain, as well as better oral care. Success with clear aligners depends on patient compliance (wearing aligners as instructed).[78-80]

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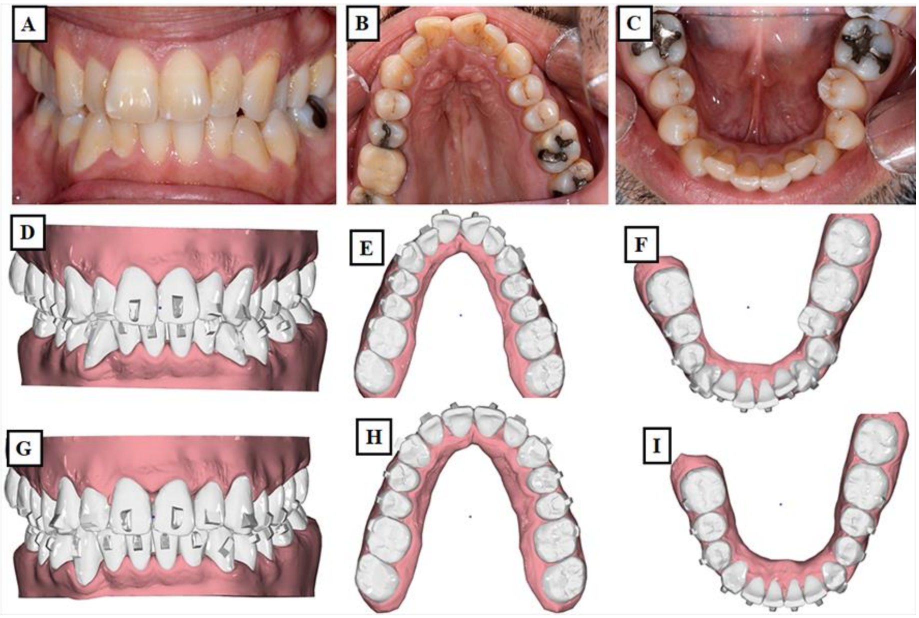

Fig. 10 A-I: Digital treatment planning of tooth movements following a precise diagnosis and calculation of the required movements for therapy with clear aligners. *A–C:* Initial clinical situation of the patient prior to treatment. *D–F:* Visualization of the planned attachments on the teeth based on the movement analysis up to the treatment goal. *G–I:* Simulation of the anticipated final outcome after completion of the aligner sequence.

Align Technology also requires accurate maxillary and mandibular impressions made in a polyvinyl siloxane material along with a bite registration, both of them are scanned to permit the fabrication of a virtual model.[80]

A physical 3D model is needed for each individual aligner of the treatment set, and it is made using 3D printing, stereolithography. Next, aligners are fabricated by molding the clear material over the 3D model of the patient's teeth (thermoforming or vacuum forming).

With the recent increase in adults seeking orthodontic treatment, there has been a corresponding increase in demand for appliances that are both more aesthetic and more comfortable than conventional fixed appliances.[77]

The formal introduction of clear aligners to the orthodontic armamentarium dates back to the 1998 FDA approval for Align Technology to employ Invisalign for orthodontic use.[78] Kesling's appliance (the positioner) was a precursor to the Invisalign aligner. In 1945, Kesling predicted the future development when he stated that: "Major tooth movements could be accomplished with a series of positioners by changUUing the teeth on the setup slightly, as treatment progresses. It remains a possibility, however, and the technique for its practical application might be developed in the future"[79]

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Clear aligner is a natural extension of the use of tooth positioners and also spring aligners for tooth alignment that have been employed by orthodontists for many decades. Recently, with advances in transparent thermoplastic materials and computer technology (CAD-CAM, stereolithography and tooth-movement simulation software), this has resulted in clear aligner products being made increasingly available and effective for tooth alignment in a variety of malocclusions.[17,78] Invisalign aligners consist of a series of clear, removable, plastic appliances that the patient wears sequentially to achieve the final result. The Invisalign system uses a computer-based online software to plan the treatment ahead of time and the orthodontist can share the expected final results with the patients. Invisalign aligners were introduced to offer not only the advantage of better esthetics but also the convenience of removal during consumption of food and beverage, less pain, as well as better oral care.[80]

3D printing could be used for direct printing of clear aligners by a single processing step using one or a combination of 3D-printing processes. Theoretically, various 3D printing processes may be used for direct printed clear aligners, such as fused filament fabrication (FFF), selective laser sintering (SLS) or melting(SLM), stereolithography (SLA), multi-jet photocured polymer process, HP MultiJet Fusion technology or continuous liquid interface production technology[13,77]

There are multiple clear resins used for 3D printing of appliances. In early 2018, EnvisionTEC announced the commercial release of E-Ortholign, an innovative material for the direct 3D printing of clear aligners. Objectively, the direct 3D printing of aligners offers several advantages over conventional fabrication **[77] :**

1. borders are digitally designed and identically reproduced for all sets of aligners;

2. edges are smooth and do not need trimming or polishing;

3. undercuts do not exist because they are digitally defined;

4. aligners are fabricated with higher precision as there are no errors introduced during printing of a 3D molding model and thermoforming stage of fabrication;

5. higher precision leads to better fitting and higher effectiveness;

6. aligner thickness is customizable, and this may reduce the need for attachments, which generally lower the transparency of clear aligner

Treatment with the Invisalign® system ultimately requires the use of ‘attachments’ akin to fixed appliance brackets. These small, custom-made composite shapes are bonded onto specific teeth in a manner similar to brackets. Attachments serve three main advantages : assistance with difficult movements, the augmentation of anchorage and support for auxiliary functions. **[13,15]**

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Clear aligners provide advantages over treatment with traditional fixed appliances. These include fewer clinical emergencies and improved aesthetics, comfort, oral hygiene, periodontal health, and lack of soft tissue irritation . However, a significant limitation of the Invisalign system is the difficulty to alter the course of treatment once the set of aligners has been fabricated. If the final therapy outcome is unsatisfactory, the clinician may need to resort to the use of auxiliary devices (fixed attachments such as brackets), or request the fabrication of additional aligners **. [13,15]**

The orthodontic industry must explore innovative solutions to reduce the environmental impact of clear aligners and other appliances. Researchers are investigating new materials, such as shape memory polymers and bioactive substances, that could replace conventional plastics and reduce the number of aligners needed, thus lowering plastic consumption. Direct 3D printing of clear aligners from digital designs is another promising development that could streamline production, reduce waste, and eliminate the need for thermoforming

and polishing. This method offers higher precision, better fitness, and improved patient outcomes while minimizing the environmental footprint. However, further research is required to ensure these materials' durability, safety, and costeffectiveness. **[13,14,15]**

Additionally, using recycled materials in 3D printing could

enhance sustainability by reducing dependence on virgin plastics and lowering the manufacturing process's environmental impact, making orthodontic practices more eco-friendly.[81-83]

Digital smile design

DSD or digital smile design, basically, involves the use of digital imaging software to create a virtual 3D model of the teeth and gums of a patient. This model can then be used to design a custom treatment plan to improve the appearance of the smile. This technology can also be used to show patients what their smile will look like post-treatment, thus helping them make informed decisions about their dental care [13-21,33,84].

Teledentistry

Teledentistry, as aforementioned, is a form of telemedicine, involving digital technologies to provide dental care and consultation remotely, where patients can receive dental consultations, screenings, and even some treatments without needing to visit a physical dental office (so, increasing convenience and reducing costs). It is particularly useful for patients in isolated, distant, or underserved areas who maynot have access to dental care. Teledentistry can also be used for follow-up appointments, consultations, and monitoring of patients who have undergone dental procedures. Today, teledentistry is a rapidly growing area of digital dentistry,particularly in the wake of the COVID-19 pandemic, improving access to care,

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treatment outcomes and reducing the risk of disease transmission via enabling the early detection and treatment of oral and dental problems [13,14, 85].

Role Of Robots In Orthodontics

Robotic technology in medical field has been extensively researched in developed countries. Robots in dentistry can be employed to bring convenience, improve accuracy and provide economic growth. Although in a nascent stage, robots in orthodontics can be used for inserting a mini-implant with precise insertion depth, insertion angle, proper torque and achieving primary stability.[13,86] Robots have also been employed to bend arch-wire and is known as SureSmile arch-wire bending robot.They provide with customized arch-wire and brackets allowing simulation of different treatment plans and detailed treatment planning.[87] The scope of robotic technology in vast and unlimited but will require extensive research to promise practical clinical benefit in this field.[15,86,87]

Orthodontic Research

It should not come as a surprise that digital technology has a big impact on orthodontic research. For many years, comparing pre- and post-treatment two-dimensional cephalograms or manually measuring changes on plaster casts were the primary methods used to evaluate the clinical treatment effects. The effects of orthodontic, orthopaedic, and orthognathic surgery can affect the teeth and surrounding bones as well as the facial soft tissues and airways, thanks to the recent development of 3D superimposition techniques of study models and CBCTs/CT scans (46, 47). As radiation dosages are decreased, it is almost clear that this will soon become the norm for assessing treatment outcomes. Additionally, finite element models can be built with a high degree of realism to accurately simulate the influences of the real environment, enabling improved modelling of biomechanics for orthopaedic therapies and orthodontic tooth movement.[12-21,88,89]

The use of microCT enables a much closer look of alterations to the bone and root at the microscopic level. A better understanding of tissue changes with orthodontic treatment is provided by the 3D visualisation and assessment of volumetric changes and resorption craters.[14,90]

Clinical CBCTs and scanners are projected to gradually improve in resolution and reduce radiation levels, allowing for the availability of information that is currently only accessible through a high radiation microCT using standard clinical scanners. This will make root canal treatments (RCT) simpler in terms of determining the root canal's shape, cleaning and filling it, and lastly determining whether the RCT was successful .[15,88,90,91]

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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.[13]

- 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).

Conclusion:

Orthodontics is inclining digitally in every possible aspect for a better quality treatment. Replacing digital with the manual type, saves time and easy chair side routine for the orthodontists. Like recent advancement in the concern of ortho braces , invisalign set a trend by adding up more to orthodontic correction and also adding up to patients esthetics .Orthodontics is an interdisciplinary department which definitely needs digitalisation to provide quality treatment and time saving.[13,14,15,92]

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