Available online at https://www.mmpubl.com/

International Journal of Community Dentistry

Review Article

Digital Orthodontics - Current State And Prospects

Karthikeyan M [1] Shanthinipriya A [2] Balaji Krishnan[3] Jayaraj Ravi[1] Lokeswari P[1] Daffy jacentha S[1]*

1Post graduate student, Department of Orthodontics, Tagore dental college, Chennai

2 Senior lecturer, Department of Orthodontics, Tagore dental college, Chennai*

3 Professor and Head of the department, Department of Orthodontics, Tagore dental college, Chennai

How to cite: Karthikeyan M, Shanthinipriya A, Balaji Krishnan, Jayaraj Ravi, Lokeswari P, Daffy jacentha S. Digital Orthodontics - Current state and prospects. Int J Comm Dent 2024;12(1):09 - 21.

DOI: https://doi.org/10.56501/intjcommunitydent.v12i1.1108

Received: 30/07/2024 *Accepted: 13/08/2024* *Web Published: 31/08/2024*

ABSTRACT

The world is transitioning to a digital age, and orthodontics is no exception. The use of technology in orthodontics has risen dramatically, and computer literacy is no longer rudimentary. Since the invention and development of mobile phones, digital technology has h a huge impact on our daily lives. 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.

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

Address for Correspondence:
Shanthinipriya A,
Senior lecturer, Department of orthodontics, Tagore dental college, Chennai - 600127
Email-Id: **shanthinipriyaarumugam@gmail.com**

INTRODUCTION

Advances in technology has made the life of the orthodontists simpler, it aids the orthodontist to plan and execute the treatment more efficiently. Integrating current technology is crucial for the success of an orthodontic practise. Thanks to globalisation, we now have access to the best resources available in the field of orthodontics, enabling us to provide our patients with high-quality care. Orthodontic treatment begins with a proper diagnosis, an excellent treatment plan is based on an accurate diagnostic record. There are various essential and supplemental diagnostic aids. Detailed histories, extra oral and intraoral examinations, study models, photographs, and radiographs are all crucial diagnostic aids (1, 2).

An orthodontist's primary responsibility is to realign various craniofacial components in anatomical and dynamic balancing positions in order to improve their aesthetic appeal. However, in order to complete this procedure, Orthodontists require knowledge of the relationships among all of these craniofacial complex components in three spatial planes. The majority of the current diagnostic tools on the market only gives patient a 2-dimensional depiction. This article reviews the latest advancements in digital 3D technology for orthodontic diagnosis and appliance production (3).

3D Orthodontic Diagnosis and Treatment Planning

Nowadays, study casts and impressions have mostly been supplanted by intraoral scanners. The accuracy of the scans is as good as that of plaster models (4). Patients find the scanning process more comfortable, especially now that their gag response is lessened. Without the need for packing and sending impressions, they can be conveniently saved and shared online with any dental laboratory worldwide. Additionally, this eliminates two potential sources of inaccuracy and material variability in the handling, pouring, and manipulation of plaster casts when taking impressions (5). The lab can use the digital files to directly create and produce digital appliances or to print them out as physical models (6).

Three-dimensional radiography, such as CBCT, is gradually replacing traditional two-dimensional radiography (7). It is impossible to overstate the benefits of CBCTs for diagnosis, particularly in instances including eruption concerns, TMJ problems, complex orthognathic surgery cases, and the need to identify and diagnose pathologic structures in the maxilla and face region as well as root proximities, root resorption, and impacted teeth. For precise diagnosis and treatment planning, it is essential to be able to quickly and properly analyse the location and condition of the teeth and bones in all three dimensions. CBCT scans can also be used to assess airway dimensions and potential obstructions, which is important for patients with breathing difficulties or obstructive sleep apnea. CBCT imaging is crucial in orthodontics for evaluating impacted canines, (figure 1) determining labial/lingual relationships, angulation, and proximity of adjacent roots. It aids in uncovering and bonding, and determining the appropriate force vector for tooth movement. Orthopantomograms and radiographs are used to view root resorption, but have limitations. CBCT images provide clear view of root resorption (figure 2), easy-to-classify information, especially for teeth with multiple roots. CBCT allows for easy viewing of root fractures in all three planes of space, making it easier to determine the fracture site and displacement degree. Three-dimensional visualization aids in accurate evaluation of dental and skeletal asymmetries, enabling easier determination of unilateral crossbite and centric occlusion in maxillary and mandibular bones. CBCT technology enhances airway analysis, (Figure 3) enabling 3D and volumetric analysis, making it a valuable tool for diagnosing and managing complex clinical conditions like sleep apnea and enlarged adenoids (8) (Figure 3).

Orthodontists can use 3D models to plan treatment more effectively. They can visualize tooth movements in three dimensions (Figure 4), simulate treatment outcomes and design customized treatment plans tailored to each patient's unique anatomy.

With the addition of 3D facial photos to digital study models and CBCTs, a full three-dimensional virtual image of the patient is now achievable.9 The intraoral scan can now be combined with CBCT scans of hard tissues (Figure 5) and 3D facial images using a variety of software platforms. Furthermore, to have a complete portrayal of the orthodontic patient, it is also possible to add function with mandibular movements and grin (9).

In surgical conditions, 3D technology enables orthodontist to detect bone and soft tissue changes, the use of virtual treatment planning (Figure 6) is extremely advantageous (10). For exact surgical outcomes, this can subsequently be transferred into the production and direct printing of surgical splints (11). Additionally, the ability to directly print surgical fixation plates and drill guides allows for surgical precision that has never before been possible (12,13).

Miniscrews and temporary anchorage devices can both benefit from the same technology to boost their effectiveness. The quality and thickness of the bone (Figure 7) at the site of insertion, for instance, has a significant impact on the effectiveness of TADs. In order to ensure that the TADs are placed in the best possible sites, implant insertion guides can be produced utilising CAD/CAM technology by combining intraoral images and CBCT data. Additionally, it is possible to produce TAD-supported appliances in advance using the same models, allowing the TADs and the appliances to be installed at the same visit, significantly cutting down on chair time while improving accuracy and efficiency for both the operator and the patient (14). 3D images and simulations help patients to understand their orthodontic conditions better. Orthodontists can visually explain treatment options and expected outcomes, leading to improved patient communication and satisfaction.

Digital Workflow in Appliance Manufacturing

The "Digital Workflow in Appliance Manufacturing" (Figure 8) refers to the streamlined process of designing and producing orthodontic appliances using digital technologies. This approach leverages computer-aided design (CAD), computer-aided manufacturing (CAM), and other digital tools to enhance efficiency, accuracy, and customization in appliance manufacturing. CAD/CAM technology has been used in dentistry for almost 30 years, and it has found its way into orthodontics by means of the printing of aligner treatment models, direct printing of brackets, and robotic wire bending.

Align Technology pioneered the use of virtual models to create appliances for clear aligner therapy with Invisalign®, achieving pre-determined treatment outcomes. Planning is done in advance for the positioning of attachments to regulate tooth movement, the requirement for interproximal reduction and/or extractions, and the planning for inter arch mechanics. Before beginning treatment, this technique enables the patient to evaluate the results and the operator to visualise their treatment mechanics and the tooth movement process.

Fixed appliance therapy has also evolved as a result of digitization. Over 15 years ago, Dr. Wiechmann (15) pioneered the use of fully customised lingual appliances by combining virtual setups, customised bracket printing, and robotic wire bending. Fully customised brackets are digitally built to adapt as precisely as possible to the lingual surface of the teeth, and they are then 3D printed in wax before being cast in gold. This process begins with the creation of a virtual setup with the intended treatment outcome. This made it possible to design a lingual appliance with a low profile that closely resembles the lingual tooth surfaces while causing the tongue less discomfort (16). To obtain the intended results, the wires were then robotically bent to match each particular lingual arch form. The end result is an appliance that is completely customised, highly precise, and less uncomfortable.

With the launch of Insignia (17) by ORMCO (Ormco, Glendorra, CA, USA), a system of customised labial appliances that are subsequently indirectly bonded, this technique has also been used to labial appliances. Even though the majority of orthodontists use a type of straight wire appliance, precision wire bending is still necessary, particularly during the last stages of treatment. This can take a lot of time and need a lot of sitting. A digital platform made available by Suresmile enables intraoral scanning even with fixed appliances in place (18). The wires are then robotically bent with extreme precision to provide the appropriate finish using the models as a guide. The system's ability to work with any brand or category of fixed appliances is a benefit. Additionally, CBCT data can be combined to provide precise root location and to enable functioning inside the patient's specific bone envelope. The use of the facial images allows for the creation of a 3D smile. According to studies, this use of technology can cut the length of fixed appliance treatments by up to 35% (19, 20).

In addition to the production of customised brackets, digital technology now enables the creation of indirect bonding trays and virtual bracket positions (21, 22). A business uses a virtual straight wire to model results, correct bracket positioning mistakes, and produce indirect bonding trays for precise bracket placement, reducing treatment times.

Direct Appliance Manufacturing

Direct appliance manufacturing in 3D printing refers to the process of fabricating orthodontic appliances directly from digital designs using additive manufacturing techniques. This approach leverages the capabilities of 3D printing to produce customized orthodontic devices with high precision and efficiency. 3D printing is a highly accurate method for creating customized orthodontic appliances, reducing production time and labour costs by eliminating intermediate steps like model-making. It can produce complex geometries and intricate designs, making additive manufacturing more material-efficient. Rapid prototyping and iteration of designs enable continuous improvement and customization (23).

Recently, laser melting technology has made it possible to directly print metallic appliances. By employing CAD/CAM technology to virtually design and then directly print maxillary expansion appliances, Graf et al pioneered the use of LASER melting to create these appliances (24).

The retention stage after orthodontic treatment is crucial for maintaining occlusion. 3D printer models can eliminate problems like patient loss or degradation. In 2014, Nasef et al designed a virtual Essix retainer using CBCT images and SLS 3D printing (25). In 1996, Sassani and Roberts created the first partially autonomous acrylic orthodontic devices made with 3D printers (26). Salmi et al. created two soft detachable items with SLA printing. Al Mortadi et al utilised SLA printing's stop facility for their own designs and sleep apnoea devices (27). This innovative approach offers hope for future designs. 3D printers have been used to produce various orthodontic auxiliaries, such as a customized chain for impacted canine teeth and retraction hooks. These devices can be developed with software such as Netfabb and produced with FDM or SLA printing. The main advantage of 3D printers is their ability to produce customized devices, which could quickly replace older technologies. Rapid prototyping technology has also been used to guide auto transplantation processes. Trends in patient-specific devices have influenced orthodontists' choice of bracket types. Researchers have used digital models to determine bracket positions and design tooth- compatible bases. They also created a Herbst appliance for bespoke lingual brackets. Krey et al devised an all-digital workflow to create personalised braces and archwires (28). Yang et al utilised DLP printing to transform virtual bracket models into wax patterns (29).

Duarte et al produced transfer trays for orthodontists and found that digitally-planned brackets and transfer tray positions were generally compatible (30). Plater et al found that the digital laboratory process was longer, while chair time per patient was shortened (31).

The use of 3D printers and digital workflows has enhanced the effectiveness of occlusal splints in treating temporomandibular joint problems. These innovations have resulted in shorter lab processes, labour, and patient wait times as compared to old production methods. Studies have shown that 3D-printed splints are as successful as traditional methods and can fit better on teeth. 3D printers are also used in surgery for intermediate and final splints, such as orthognathic surgery (32). Studies have shown a wide error range but acceptable accuracy, and a reduced error rate in 3D final occlusal splints (33, 34).

Digital technologies have significantly impacted the treatment protocol for patients with cleft lip and palate. The advent of intra oral scanner has reduced the risk of aspiration. Shen et al used CAD software to develop orthopaedic devices that used Grayson and Cutting's therapy procedure, closing the space between alveolar bones by 1 mm each week (35). Grill et al investigated NAM devices using CAD/CAM technology and Rapid-NAM, which automatically identifies alveolar ridges and designs plates according to healthy newborn growth data (36). Zheng et al used "split type-NAM devices" to separate the nasal hook and NAM devices, resulting in improved cleft distance, arch form, lip segment proximity, and nasal morphology (37). Bous et al case series combined clear aligners and presurgical infant orthopedics, producing models using FFF printing for a unilateral cleft lip-palate. Full digital workflows have been found to be easier to treat patients and reduce patient visits and chairside visits (38).

3D printers have been used to create customized surgical guides (Figure 9) for precise placement of miniscrews, avoiding anatomical structures like dental roots and thin bones. These guides are reliable and can be used in clinical practice. Researchers have used models from 3D printers to create jigs from light-cured resin material, such as the MAPA system for palatal miniscrew placement. Additionally, 3D printers have been used to guide corticotomies to accelerate orthodontic tooth movement (39-41).

This makes it possible to produce conventional metallic banded appliances without using the conventional separation, band-fitting, and digital imprints processes. Without the creation of any models, the appliances are produced and prepared for immediate installation. There are several benefits, including the first one, which is the elimination of separation and impression-taking pain, and the second, which is the reduction in chair time. Additionally, the virtual appliance design allows for a lot of design flexibility and extremely accurate fitment. It is especially promising to use digital processes for the design and production of TAD- borne devices. Planning the location of the mini-implants enables the best insertion position to be determined using digital models and, if desired, radiography. Implant insertion and appliance installation can be completed in a single session by using printed insertion guidelines (42) or the device itself (43).

The possibility of screw overloading and, thus, the chance of implant failure can be minimised because of the accurate fitting (44, 45). The benefits of digital processes can be limited by some dangers, though, as they depend on the operator's abilities and expertise.

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.

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.

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 (48, 49)

Compliance Monitoring

It has always been difficult to get patients to comply with orthodontic treatment plans, especially when they require them to wear removable appliances or elastics (50). Additionally, studies have shown that patients may think they are more compliant than they actually are. Failure or a delay in orthodontic treatment might result from poor or low compliance. Reporting the findings of a study on compliance-dependent treatment is especially crucial because the compliance component considerably skews the data. Digital monitoring technology has been included into appliances, revealing that patients' reports of compliance are undoubtedly false (51).

The customised and gamification of facemask use is a very cutting-edge strategy used by an Italian company called SuperPowerMe (52). Integrating sensors within the appliance allows us to not only assess compliance, but also link with a smart device software that changes into a computer game, as well as a 3D printed customised facemask for added comfort. Only with the facemask on can the kid play the game and advance to specific levels. This not only promotes compliance but also makes donning the facemask more enjoyable.

Remote Monitoring

People rely more and more on internet purchasing and remote access to everything in today's hectic environment. In a way, Dental Monitoring is applying this to orthodontics (Dental Monitoring SAS Paris, France). Patients can communicate their progress to the managing orthodontist using the app by taking routine progress scans of their teeth and faces using a smartphone. In this manner, patients are not obliged to physically visit the office until an adjustment is required. This can make treatment less time-consuming for the busy patient and family, and it can free up significant chair time for progress checks in the orthodontic office. The technology can be used in conjunction with 3D installations to great effect, allowing patients to be reminded to visit the office after the wire has turned inactive.

The device can notify the patient and the orthodontists during clear aligner therapy if there is a slight mismatch on the aligner or if a tooth or group of teeth are not moving in accordance with the intended plan. The programme has gone a step further by providing the patient with real- time information on their readiness to go on to the next aligner.

Fixed retainers alone have the ability to move or deform teeth. Remote monitoring, however, makes it feasible to spot slight changes early and notify the patient and their orthodontists that a review of the retainers is necessary.

There are risks and drawbacks to using digital technology. The rise of the DIY orthodontic market is also due to the greater accessibility of 3D printers and digital technologies. There have been a number of recent stories of patients using DIY appliances to try their own orthodontic treatment. Additionally, businesses are now offering direct delivery aligners without the patient first needing an orthodontist to properly analyse and diagnose them, with all of the hazards that entails.

Rapid prototyping and 3D printing's ease of use and availability are also anticipated to significantly alter orthodontic production as we currently know it. Most office appliances will be able to be produce without the requirement for pre-manufactured parts thanks to in-house printers. This will have a severe detrimental effect on the orthodontic manufacturing sector, and it might make it difficult for regulators to keep track of the calibre of these appliances.

The majority of simpler situations will likely be handled in the very near future by either DIY orthodontic providers or automated services using mail-order appliances. Specialists in orthodontics will still be needed, particularly for the treatment of more severe malocclusions. However, rather than in the clinic, more work will be done in front of computers, tablets, and smartphones (53).

Orthodontic Education and Scientific Societies

Having rapid responses and instant access to expertise and information becoming the norm, more and more orthodontists and specialists are using social media for information and discussion forums. Scientific societies are quickly being replaced by online forums, and the traditional model of peer-reviewed journals and scientific meetings will need to quickly adapt and innovate in order to keep up. Online live chat and video lectures are quickly taking over as the mainstay of education (53).

CONCLUSION

With the advent of 3D printers and scanners that have solved issues with clay models and storage, the burden associated with the conventional process is being reduced as new appliances are created at a lower cost. This is creating a digital workflow in place of the conventional one. Despite initially concentrating mostly on 3D-printed models, researchers are now using 3D printers to make orthodontic equipment or attachments. While gadgets with acrylic components and clasps have not yet been produced in a single step, technical advancements show promise. In conclusion, digital orthodontics has transformed orthodontic practice by enhancing diagnostic accuracy, treatment customization, and overall efficiency. As technology continues to evolve and integrate with AI, the field is poised to deliver even more personalized, effective, and patient-centered orthodontic care in the years to come.

FINANCIAL SUPPORT AND SPONSORSHIP

Nil

CONFLICTS OF INTEREST

There are no conflicts of interest

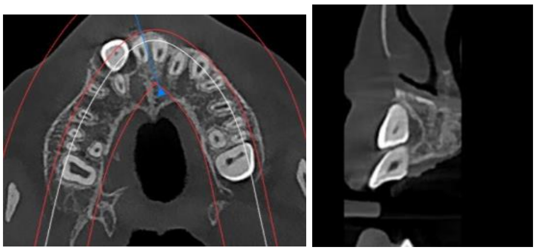


Figure 1 - Impacted canine position assessment

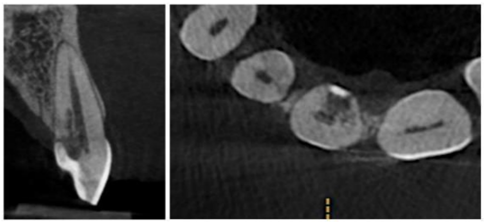


Figure 2 - Root resorption

Figure 3 - Airway analysis and adenoid examination

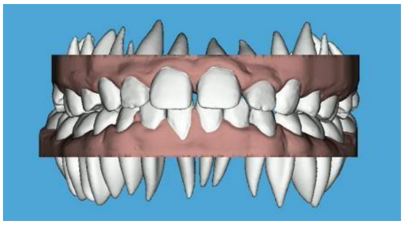


Figure 4 - 3D tooth movements before

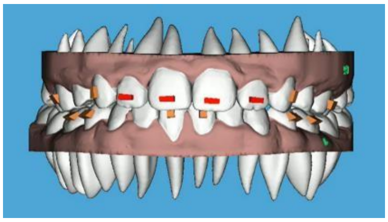


Figure 4 - 3D tooth movements after

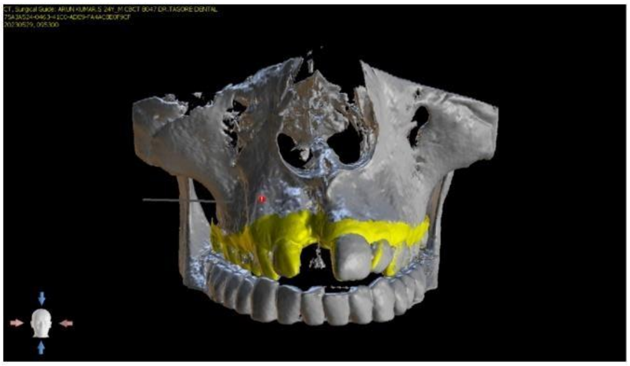


Figure 5 - CBCT + Intra oral scan merge

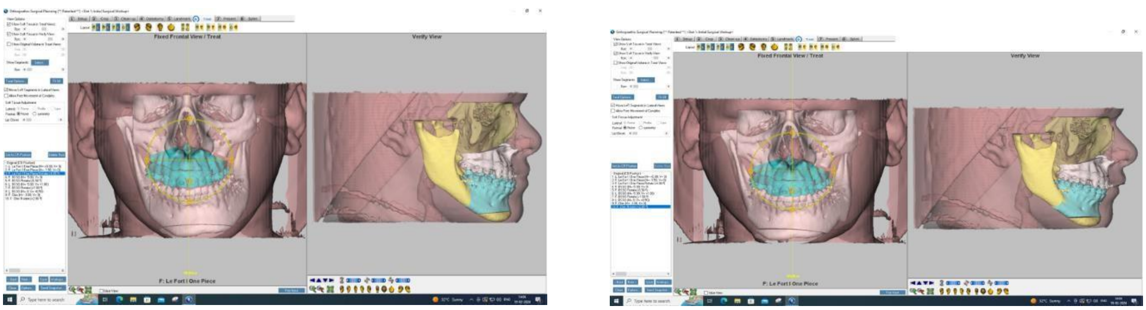


Figure 6 - Surgical VTO

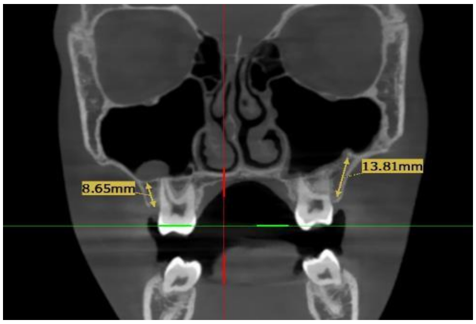


Figure 7 - Measuring the bone thickness

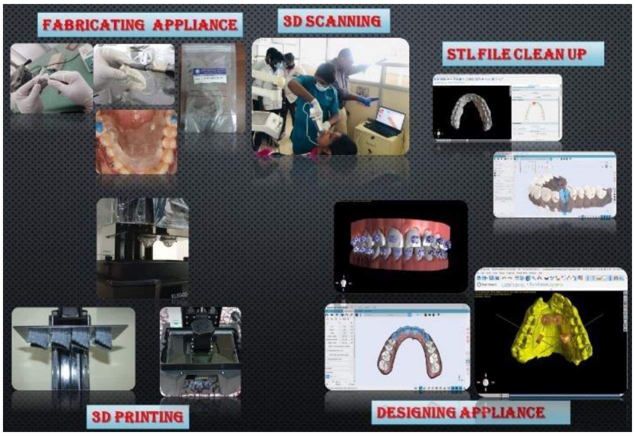
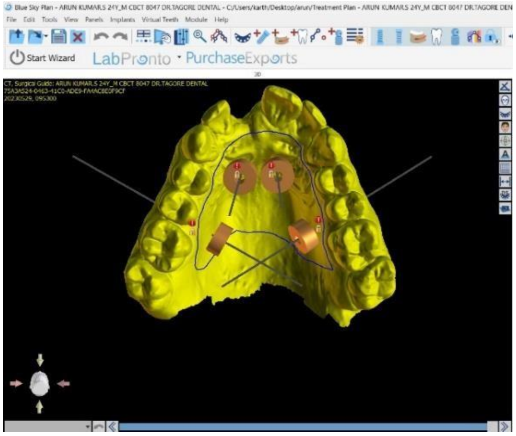


Figure 8- Digital workflow



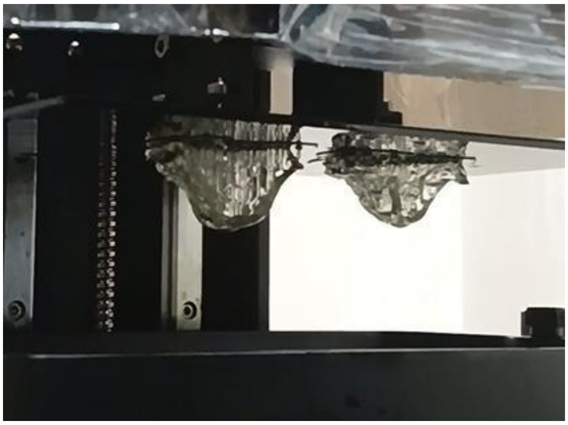


Figure 9 - Virtual planning of surgical guide

REFERENCES

1. Ahmed Mohammed Alassiry. Digital Orthodontics- A contemporary view of futuristic practice Int. J. of Adv. Res. 9 (Apr), 2021; 723-732.

2. Tarraf Nour Eldin, Darendeliler M. Ali. Present and the future of Digital Orthodontics, Seminars in Orthodontics (2018), doi: https://doi.org/10.1053/j.sodo.2018.10.002

3. Bhardwaj A. Digital Orthodontics- A Technology in Modern Practice, Present scenario with Clinical implications. Annals and Essences of Dentistry, 2023; 15:247.

4. Vögtlin C, Schulz G, Jäger K, Müller B. Comparing the accuracy of master models based on digital intra-oral scanners with conventional plaster casts. Physics in Medicine. 2016 Jun 1;1:20-6.

5. Ahmed S, Hawsah A, Rustom R, Alamri A, Althomairy S, Alenezi M, Shaker S, Alrawsaa F, Althumairy A, Alteraigi A. Digital Impressions Versus Conventional Impressions in Prosthodontics: A Systematic Review. Cureus. 2024 Jan;16(1).

6. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. Orthod Craniofac Res. 2011;14(1):1-16.

7. Randolph R. Resnik, John W. Preece, Radiographic Complications and Evaluation, Misch's Avoiding Complications in Oral Implantology, 2017.

8. Agrawal JM, Agrawal MS, Nanjannawar LG, Parushetti AD. CBCT in orthodontics: the wave of future. The journal of contemporary dental practice. 2013 Jan 1;14(1):153.

9. Park JH, Lee GH, Moon DN, Yun KD, Kim JC, Lee KC. Creation of Digital virtual patient by integrating CBCT, Intraoral scan, 3D facial scan: an Approach to Methodology for Integration Accuracy. Journal of Craniofacial Surgery. 2022 Jun 1;33(4):e396-8.

10. Cevidanes LH, Tucker S, Styner M, Kim H, Chapuis J, Reyes M, et al. Three dimensional surgical simulation. Am J Orthod Dentofacial Orthop. 2010;138(3):361- 71.

11. Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Berge SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg. 2011;40(4):341- 52.

12. Aboul-Hosn Centenero S, Hernandez-Alfaro F. 3D planning in orthognathic surgery: CAD/CAM surgical splints and prediction of the soft and hard tissues results - our experience in 16 cases. J Craniomaxillofac Surg. 2012;40(2):162-8.

13. De Riu G, Meloni SM, Baj A, Corda A, Soma D, Tullio A. Computer-assisted orthognathic surgery for correction of facial asymmetry: results of a randomised controlled clinical trial. Br J Oral Maxillofac Surg. 2014;52(3):251-7.

14. De Gabriele O, Dallatana G, Riva R, Vasudavan S, Wilmes B. The easy driver for placement of palatal mini-implants and a maxillary expander in a single appointment. J Clin Orthod. 2017;51(11):728-37.

15. Wiechmann D, Rummel V, Thalheim A, Simon JS, Wiechmann L. Customized brackets and archwires for lingual orthodontic treatment. American Journal of Orthodontics & Dentofacial Orthopedics. 2003;124(5):593-9.

16. Grauer D, Proffit WR. Accuracy in tooth positioning with a fully customized lingual orthodontic appliance. Am J Orthod Dentofacial Orthop. 2011;140(3):433-43.

17. Gracco A, Tracey S. The insignia system of customized orthodontics. J Clin Orthod. 2011;45(8):442-51; quiz 67-8.

18. Mah J, Sachdeva R. Computer-assisted orthodontic treatment: the SureSmile process. Am J Orthod Dentofacial Orthop. 2001;120(1):85-7.

19. Saxe AK, Louie LJ, Mah J. Efficiency and effectiveness of SureSmile. World J Orthod. 2010;11(1):16-22.

20. Sachdeva RC, Aranha SL, Egan ME, Gross HT, Sachdeva NS, Currier GF, et al. Treatment time: SureSmile vs conventional. Orthodontics (Chic). 2012;13(1):72-85.

21. Groth C, Kravitz ND, Shirck JM. Incorporating three-dimensional printing in orthodontics. J Clin Orthod. 2018;52(1):28-33.

22. Kravitz ND, Groth C, Shannon T. CAD/CAM software for three-dimensional printing. J Clin Orthod. 2018;52(1):22-7.

23. Al Mortadi N, Jones Q, Eggbeer D, Lewis J, Williams RJ. Fabrication of a resin appliance with alloy components using digital technology without an analog impression. Am J Orthod Dentofacial Orthop. 2015;148(5):862-7.

24. Graf S, Cornelis MA, Hauber Gameiro G, Cattaneo PM. Computer-aided design and manufacture of hyrax devices: Can we really go digital? Am J Orthod Dentofacial Orthop. 2017;152(6):870-4.

25. Nasef AA, El-Beialy AR, Mostafa YA. Virtual techniques for designing and fabricating a retainer. Am J Orthod Dentofacial Orthop. 2014;146(3):394-398.

26. Sassani F, Roberts S. Computer-assisted fabrication of orthodontic appliances. Comput Ind. 1996;29(3):179-195.

27. Al Mortadi N, Jones Q, Eggbeer D, Lewis J, Williams RJ. Fabrication of a resin appliance with alloy components using digital technology without an analog impression. Am J Orthod Dentofacial Orthop. 2015;148(5):862-867.

28. Krey KF, Darkazanly N, Kühnert R, Ruge S. 3D-printed orthodontic brackets - proof of concept. Int J Comput Dent. 2016;19(4):351-362.

29. Yang L, Yin G, Liao X, Yin X, Ye N. A novel customized ceramic bracket for esthetic orthodontics: in vitro study. Prog Orthod. 2019;20(1):39.

30. Duarte MEA, Gribel BF, Spitz A, Artese F, Miguel JAM. Reproducibility of digital indirect bonding technique using three-dimensional (3D) models and 3D-printed transfer trays. Angle Orthod. 2020;90(1):92 99.

31. Plattner J, Othman A, Arnold J, von See C. Comparative study between the overall production time of digitally versus conventionally produced indirect orthodontic bonding trays. Turk J Orthod. 2020;33(4):232-238.

32. Salmi M, Tuomi J, Sirkkanen R, Ingman T, Mäkitie A. Rapid Tooling Method for Soft Customized Removable Oral Appliances. Open Dent J. 2012;6:85-89.

33. Ye N, Wu T, Dong T, Yuan L, Fang B, Xia L. Precision of 3D-printed splints with different dental model offsets. Am J Orthod Dentofacial Orthop. 2019;155(5):733-738.

34. Shaheen E, Coopman R, Jacobs R, Politis C. Optimized 3D virtually planned intermediate splints for bimaxillary orthognathic surgery: A clinical validation study in 20 patients. J Craniomaxillofac Surg. 2018;46(9):1441-1447.

35. Shen C, Yao CA, Magee W 3rd, Chai G, Zhang Y. Presurgical nasoalveolar molding for cleft lip and palate: the application of digitally designed molds. Plast Reconstr Surg. 2015;135(6):1007 101515.

36. Grill FD, Ritschl LM, Bauer FX, et al. A semi-automated virtual workflow solution for the design and production of intraoral molding plates using additive manufacturing: the first clinical results of a pilot-study. Sci Rep. 2018;8(1):11845.

37. Zheng J, He H, Kuang W, Yuan W. Presurgical nasoalveolar molding with 3D printing for a patient with unilateral cleft lip, alveolus, and palate. Am J Orthod Dentofacial Orthop. 2019;156(3):412-419.

38. Bous RM, Kochenour N, Valiathan M. A novel method for fabricating nasoalveolar molding appliances for infants with cleft lip and palate using 3-dimensional workflow and clear aligners. Am J Orthod Dentofac Orthop. 2020;158(3):452-458.

39. Maino G, Paoletto E, Lombardo L, Siciliani G. MAPA: a New High precision 3D Method of Palatal Miniscrew Placement. Eur J Orthod. 2015;3(2): 41-47.

40. Sánchez-Riofrío D, Viñas MJ, Ustrell-Torrent JM. CBCT and CAD-CAM technology to design a minimally invasive maxillary expander. BMC Oral Health. 2020;20(1):303.

41. Hou H, Li C, Chen M, et al. A novel 3D-printed computer-assisted piezocision guide for surgically facilitated orthodontics. Am J Orthod Dentofac Orthop. 2019;155(4):584- 591.

42. Becker, K.; de Gabriele, R.; Dallatana, G.; Trelenberg-Stoll, V.; Wilmes, B.; Drescher, D. 3-D-Planung für Implantate in der Kieferorthopädie; Quintessence Publishing: Berlin, Germany, 2018; pp. 147–154.

43. Willmann, J.; Wilmes, B.; Becker, K.; Drescher, D. Hybrid Hyrax Direct. Kieferorthopädie 2020, 34, 249–257.

44. Isidor, F. Histological evaluation of peri-implant bone at implants subjected to occlusal overload or plaque accumulation. Clin. Oral Implants Res. 1997, 8, 1–9.

45. Isidor, F. Loss of osseointegration caused by occlusal load of oral implants. A clinical and radiographic study in monkeys. Clin. Oral Implants Res. 1996, 7, 143–152.

46. Cevidanes LH, Motta A, Proffit WR, Ackerman JL, Styner M. Cranial base superimposition for 3-dimensional evaluation of soft-tissue changes. Am J Orthod Dentofacial Orthop. 2010;137(4 Suppl):S120-9.

47. Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. Am J Orthod Dentofacial Orthop. 2009;136(6):805-14.

48. Chan EK, Darendeliler MA, Jones AS, Kaplin IJ. A calibration method used for volumetric measurement of orthodontically induced root resorption craters. Ann Biomed Eng. 2004;32(6):880-8.

49. Chan E, Darendeliler MA. Physical properties of root cementum: Part 5. Volumetric analysis of root resorption craters after application of light and heavy orthodontic forces. Am J Orthod Dentofacial Orthop. 2005;127(2):186-95.

50. Lee SJ, Ahn SJ, Kim TW. Patient compliance and locus of control in orthodontic treatment: a prospective study. Am J Orthod Dentofacial Orthop. 2008;133(3):354-8.

51. Stocker B, Willmann JH, Wilmes B, Vasudavan S, Drescher D. Wear-time recording during early Class III facemask treatment using TheraMon chip technology. Am J Orthod Dentofacial Orthop. 2016;150(3):533-40.

52. Fossati M, Marti P, Goraccie C. SuperPowerMe https://www.f6s.com/super powerme 2018.

53.Tarraf NE, Ali DM. Present and the future of digital orthodontics. InSeminars in Orthodontics 2018 Dec 1 (Vol. 24, No. 4, pp. 376-385). WB Saunders.

Published by MM Publishers
https://www.mmpubl.com/ijcd