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Original Research Paper

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CURRENT TRENDS IN 3D PRINTING: AN ERA OF CUSTOMIZATION IN ORTHODONTICS

Dr Nikunj Prajapati	Post graduate student Department of Orthodontics and Dentofacial orthopaedics , Narsinhbhai Patel dental college, Visnagar
Dr Rahul Bachwani*	Assistant professor, Department of Orthodontics and Dentofacial orthopaedics, Narsinhbhai Patel dental college, Visnagar*Corresponding Author
Dr Ajay Kubavat	Professor and Head of Department of Orthodontics and dentofacial orthopaedics , Narsinhbhai Patel dental college, Visnagar,

ABSTRACT Advanced digital technology is rapidly changing the world, as well as transforming the dental profession. The entry of computer in the field of design and manufacturing has led to the emergence of new area known as Computer Aided Design and Computer Aided Manufacturing. The adaptation of digital technologies in dentistry allied with efficient processes and accurate high-strength material are replacing outdated techniques to improve overall patients experience and outcome. CAD/CAM systems have been used for many years in various industries, notably the automotive industry, but are now finding application development in dentistry. In this article, we review the recent history of development and application of CAD/CAM in orthodontic field of Dentistry. The ability to consistently fabricate dimensionally accurate custom made orthodontic appliances in large quantities is a manufacturing challenge that has only recently been met through advances in CAD/CAM technology.

KEYWORDS : CAD/CAM, 3D Printing, Customized appliance , Orthodontics

INTRODUCTION

Rapid development of digital technologies in dentistry began in 1980s with the implementation of computer-aided design and computer-aided manufacturing (CAD/CAM) in prosthodontics for chairside fabrication of the first ceramic inlay with the Cerec 1 system.[1,2]

Nowadays, further developments of CAD/CAM allowed for integration of the technology in other fields of dentistry, including maxillofacial surgery, dental implantology and orthodontics. The main requirement to diversify the range of CAD/CAM applications is the progress in manufacturing technologies. Manufacturing can be held either with subtractive or additive methods. The digital revolution is changing the workflow and consequently changing operating procedures also.[3]

This technology has several advantages including accurate measurement, storage and time-saving as well as online consultation and presentation providing information exchange with different centers for planning and appraising medical procedures and treatment. Even teaching and research tools greatly benefited from these innovation with software for teaching dentistry, digital archiving of patient records and convenient/rapid sharing of them over the internet, digital bibliographic assistance in dental research or other utilities.[4]

Innovations in computer hardware and software, and 3D technologies offer the ability for customized treatment and biomechanical planning that will be more precise, predictable and reproducible.5 The objective of this article is to provide an insight regarding History, applications and recent advances of CADCAM technology in orthodontics.

HISTORY

Computer-aided design and manufacturing were developing in the 1960s for use in the aircraft and automotive industries and were first applied to dentistry a decade later. In Dentistry, the major development of dental CAD/CAM systems occurred in the 1980s. Dr. Duret was the first in the field of dental CAD/CAM development.[6]

The concept of 3D printing was first developed by Chuck Hull in 1984, when he was using ultraviolet light to cure tabletop coatings. In 1986, Hull established the 3D Systems Company to market the first machine for rapid prototyping, which he called stereolithography (SLA). Scott Crump developed fused deposition modeling (FDM), which was commercialized by Stratasys in 1990. Objet Geometries, the developer of PolyJet photopolymer (PPP) printing, was founded in 1998. Presently, market is flooded with an array of 3D printers employing variations of SLA, FDM, and PolyJet technologies.[7]

The advent of intraoral digital scanners coincided with the development of computer-aided design and manufacturing (CAD/CAM) technology and the 1984 introduction of chairside economical restoration of esthetic ceramics (CEREC).8 The first products to impact the orthodontic market were digital study models and aligners.9 Digital study models were introduced commercially in the late 1990s.10 3D Digital model were introduced commercially into the orthodontic market in 2001 by OrthoCad (Cadent, Carlstadt, NJ).8 One of the first intraoral scanners for orthodontic purposes was the iTero, introduced in 2007 (Align Technology, Santa Clara , Calif).11 In 2006, Cadent developed the in-office iTero digital impression system, which by 2008 was capable of full-arch intraoral scanning. Align Technology purchased Cadent in 2011, allowing clinicians to begin submitting 3D digital scans in place of physical impressions for the fabrication of Invisalign appliances. In October 2012, 3M ESPE introduced the True Definition scanner, enabling orthodontists to submit digital scans for Incognito custom lingual braces. Six months later, Ormco released the Lythos digital impression system for its Insignia and Clearguide appliance systems.[8]

Align Technology, Inc. developed Invisalign appliance for Orthodontic tooth movement in the USA in 1998.12 The SureSmile technology was developed and is owned by OraMetrix, a company founded in 1998 by Friedrich (Fritz) Riemeier and Dr. Rohit Sachdeva, through the merger of two medical technology companies, one U.S. based and the other German.5,13 The Incognito bracket system (TOP-Service, 3M, Germany) was developed by Dirk Wiechmann (Germany) in 2001.14,15

The Orapix system, developed in 2005 by the South Korean company Orapix, utilizes this advanced technology to digitize dental study models, making them virtually viewable to create a virtual set-up from which CAD/CAM transfer trays can be designed and generated for indirect bonding of lingual brackets.14,16,17 Ormco (Dr. Craig Andreiko) is also a pioneer in 3D orthodontics with Insignia Advanced Smile Design, the orthodontic software with personalized brackets.5,15,18 The customized lingual bracket e-Brace is a system which was developed in December 2008 in China by the Guangzhou Riton Bio- material Company based in the Guangzhou International Biotech Island, Guangdong, China.14 Dr Mark Lauren et al described Computer-based design and production of occlusal splint in 2008.19 The Lingual jet system developed in 2009 in association with Dr. Gualano and Dr.Baron by the same Korean company that developed the orapix in association with Dr Fillion.16,20,21 Harmony appliance by American orthodontics is a complete digitally customized self ligating lingual system designed by Dr. Patric Curiel in 2007 and launched in 2011.14,22,23 In India, Lingual matrix was one of the 1st customized straight wire system invented by Dr.Pravin Shetty and Dr.Manjul jain.24 In 2018 Graf et al presented an innovative method of 3D metal printing (laser melting) for rapid palatal expanders.25 In 2019 Jie Zheng at al designed and printed the intraoral molding plate (PNAM).26 In 2020, Batra et al presented one of the world's first documented Presurgical Infant Orthopedics cases treated with Clear Aligner Therapy.27

OVERVIEW OF CAD/CAM

CAD/CAM Component 1

CAD/CAM systems are composed of three major parts:

(1) A data acquisition unit, which collects the data from the area of the preparation, adjacent and opposing structures and then converts them to virtual impressions through intraoral scanners (in-office CAD/CAM or in-office CAD or image acquisition systems) or indirectly by means of a stone model generated through making a conventional impression;

(2) Software for designing virtual restorations on a virtual working cast and then computing the milling parameters; and

(3) A computerized milling device for manufacturing the restoration from a solid block of restorative material or additive manufacturing.

Processing Technique [28]

There are two type of processing techniques:

1. Additive manufacturing
2. Subtractive manufacturing

o Additive Manufacturing:- Additive manufacturing process takes the information from CAD file which is then converted to a stereolithography file. The drawing made in this process is approximated by triangles and slices which provide the information of each layer that is going to be printed.

- Rapid Prototyping / 3D Printing
- Fused Deposition Modeling
- Selective Laser Sintering
- Subtractive Technologies

1. Subtractive process also called Machining, such as milling, turning or drilling used carefully planned tool movements to cut away material from a work piece to form the desired object.

2. Consolidation process such as casting or molding, use custom designed tooling to solidify material into the desired shape.

APPLICATIONS IN ORTHODONTICS

1. DIAGNOSTIC AND WORKING MODELS: Digital models may be used for orthodontic diagnostic purposes. Diagnostic measurements performed on digital models represent high validity, reliability, and reproducibility, and thus may be regarded as an equal alternative to conventional plaster models. Moreover, rapid prototyping technology allows to manufacture many identical copies of a digital model without any risk of distortion or deformation, being available at any time.29,30

2. REMOVABLE RETAINERS: Computer-aided design and 3D printing open new possibilities in orthodontics to manufacture customized removable retainers. Al Mortadi et al. presented Hawley retainer manufacturing using intraoral scans obtained with TRIOS (3Shape, Copenhagen, Denmark), eliminating the need of conventional impression taking and pouring plaster models.14,31

3. FIXED LINGUAL RETAINERS: Memotain is a new CAD/CAM fabricated lingual retainer wire made of custom-cut nickel-titanium, as an alternative to multi-stranded lingual retainers. It was invented in 2012 by an orthodontist, Dr Pascal Schumacher from germany.14 Memotain is a CAD/CAM fabricated lingual retainer made of 0.014 * 0.014-in rectangular nickel-titanium. The wire is highly flexible and custom cut to precisely adapt to the patient's lingual tooth anatomy. it offers numerous perceived advantages to traditional multi-stranded lingual wires, including no need for wire measuring or bending, individually optimized placement, greater accuracy of fit, tighter interproximal adaptation, less tongue irritation, better durability, and resistance to microbial colonization.32

4. CUTOMIZED ORTHODONTIC APPLIANCE: For the design and fabrication of customized appliances the, stereolithographic (STL) files of the digital model is needed. Herbst appliances, rapid palatal expansion appliances, twin block appliances, splints for implant placement and surgical splints ("wafers") can be designed and fabricated in an almost total digital workflow.14 Digital titanium Herbst, Andresen, and sleep apnea appliances have been made with smooth surfaces, no sharp edges, and excellent fit on the teeth, palatal and gingival tissues.33,34 Additive manufacturing enables features such as hinge production, building threads, and wire insertion to be completed in a single build without assembly.

5. CUSTOMIZED LABIAL BRACKET SYSTEMS: An increasing amount of companies use designing software to design custom orthodontic appliances according to the wishes of the orthodontist and the patient. The use of an indirect bonding tray for accurate bracket placement and custom orthodontic wires bend by a wire bending robot will increase treatment efficiency. A popular custom system, Insignia, an Ormco system has been introduced for treating orthodontic patients with custom buccal brackets. Insignia delivers a custom solution for a range of orthodontic brackets placed on the buccal surface of the dentition. (DamonQ, Damon clear and Inspire Ice brackets). Insignia uses a very nice virtual planning system, which shows the limits of the dental arch, because the outline of the mandibular alveolar can be evaluated in the setup. Furthermore, the occlusion of the digital planning in this system can be evaluated. The base of the brackets can be individualized and the virtual bracket placement can be transferred to the dentition using indirect-bonding transfer jigs.18

6. CUSTOMIZED LINGUAL BRACKETS: A popular system for custom lingual brackets is Incognito (3M,Unitek). Recently, alternative customized lingual systems such as harmony and e-Brace/eLock have been introduced Wiechmann et al.

introduced 3D printing to create wax patterns of lingual orthodontic brackets, allowing to customize the shape of bracket base. The manufacturing process begins with virtual design of each bracket, which can be customized to fit ideally to the anatomy of lingual/palatal surface of teeth. Digital design allows to customize in – out, angulation and torque values of each bracket; thus, an individual bracket prescription is created for each patient.14-17

7. OCCLUSAL SPLINTS: Occlusal splints are contemporarily used for treatment of patients presenting with temporomandibular disorders (TMD).36 The conventional process of splints fabrication in dental laboratory requires taking alginate impressions of patient's dentition, wax bite registration, and mounting casts in articulator. Lauren and McIntyre were the first authors to publish an article, which describes digital workflow in occlusal splints manufacturing.19,35

8. TEMPLATES FOR MINISCREWS AND MINIPLATES PLACEMENT FOR ANCHORAGE: Orthodontic miniscrews and miniplates are used as a source of intraoral maximal anchorage. Precise miniplate placement and good adoption to the bone surface allows decreasing failure rates and enables the orthodontist to apply required mechanics. Hourfar et al introduced a method of customized adaptation and placement of orthodontic miniplates using CAD and 3D printing technology. 3D printed model of patient's bone fabricated on the basis of CBCT images has been used as a template to position and adopt the miniplate to the bony contour on the model. According to the authors, the main advantage of this technique is precise determination of the final position of an orthodontic miniplate prior to the surgical procedure, which significantly reduces the time needed for surgery and simplifies the process. Another advantage results from pre-operative adaptation of the plate to the bone surface, allowing for maximum contact between the miniplate and the bone, and decreasing the possibility of miniplate failure .37,38

9. CUSTOMIZED ARCHWIRES: As an alternative for bending, a set of custom wires with selected diameter, shape, elastic properties and tooth moving force values according to the prescription of the orthodontist, can be bent by a wire bending robot. The company Orametrix (Suresmile) started this wire bending service some decade ago. Suresmile uses a Copper-nickel-titanium wire bent by robot hand, a split second of intense heat is applied during the bend to create plastic deformation.13,14

ADVANTAGES

- 3D printing enables to transform digital, virtual dental model of patient's dentition into a physical model, omitting certain steps, which are conventionally required, including impression taking and model casting .
- Moreover, rapid prototyping technology allows manufacturing many identical copies of a digital model without any risk of distortion or deformation, being available at any time.
- Printed models may be used to manufacture removable orthodontic appliances, expansion appliances, indirect bonding trays, or thermoformable orthodontic aligners.3D facial imaging further provides comprehensive analysis as an aid in orthodontics, maxillofacial, plastic, and esthetic surgery. Software integration of digital models, 3D facial scans, and CBCT facilitate treatment simulations and establish a meaningful communication with patients.
- Elimination of traditional impressions and dental-cast production stages enhance practice efficiency, patient and staff satisfaction for a fully integrated digital and streamlined workflow.
- Patient digital impressions are stored in a more convenient way and can be easily transferred to any lab or an in-office milling machine for a simpler, faster, and more predictable appliance fabrication
- Time effectiveness
- Reduced labour
- Quality control

DISADVANTAGES

- The initial cost of the equipment and software is high
- The practitioner needs to spend time and money on training.
- Digital scanning requires the same type of soft tissue management, retraction, moisture control and hemostasis that is also important for conventional impression.
- CAD/CAM is ever advancing technology. Upgrades and updates are often required

CONCLUSION

In this article, we reviewed the current state and future perspectives of the application of dental CAD/ CAM systems and 3D printing technology in the field of orthodontic diagnosis, treatment planning and fabrication of state of the art customized orthodontic appliances. With the rapid development and advanced research of diverse technologies and compatible materials, it is possible to obtain single scan digital impressions, virtually design, and 3D print different types of orthodontic appliances. Software integration of digital models, 3D facial scans, and CBCT facilitate treatment simulations and establish a meaningful communication with patients. Elimination of traditional impressions and dental-cast production stages enhance practice efficiency, allows model reuse and improves appliance fit, thereby enhancing patient and staff satisfaction. New companies, scanner and printer models are emerging daily which will result in significant decline of systems cost and enhancement of material qualities.

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