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Latest Technologies In Orthodontics- A Review

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ABSTRACT
The extensive uses of technology in recent years have revolutionized all the fields including medicine and dentistry. The face of orthodontics has changed a lot from Angle's period to the present nanorobotic era in its concepts, biomaterials and technology. The digital technology has been extensively used for diagnosis, treatment planning, 3D printing, appliance systems, digital storage, integration and retrieval of data. The purpose of this article is to provide a review on the latest technologies available in the market and its various applications in Orthodontics.

Keywords: Advancements, Aligners, Digital imaging, 3D printing, latest technologies, Nanotechnology

INTRODUCTION

The future of orthodontics is digital as any other field. Evolving technology and integration of digital solutions in private practice have transformed diagnosis and treatment planning from a traditional two-dimensional (2D) approach into an advanced three-dimensional (3D) technique [1].

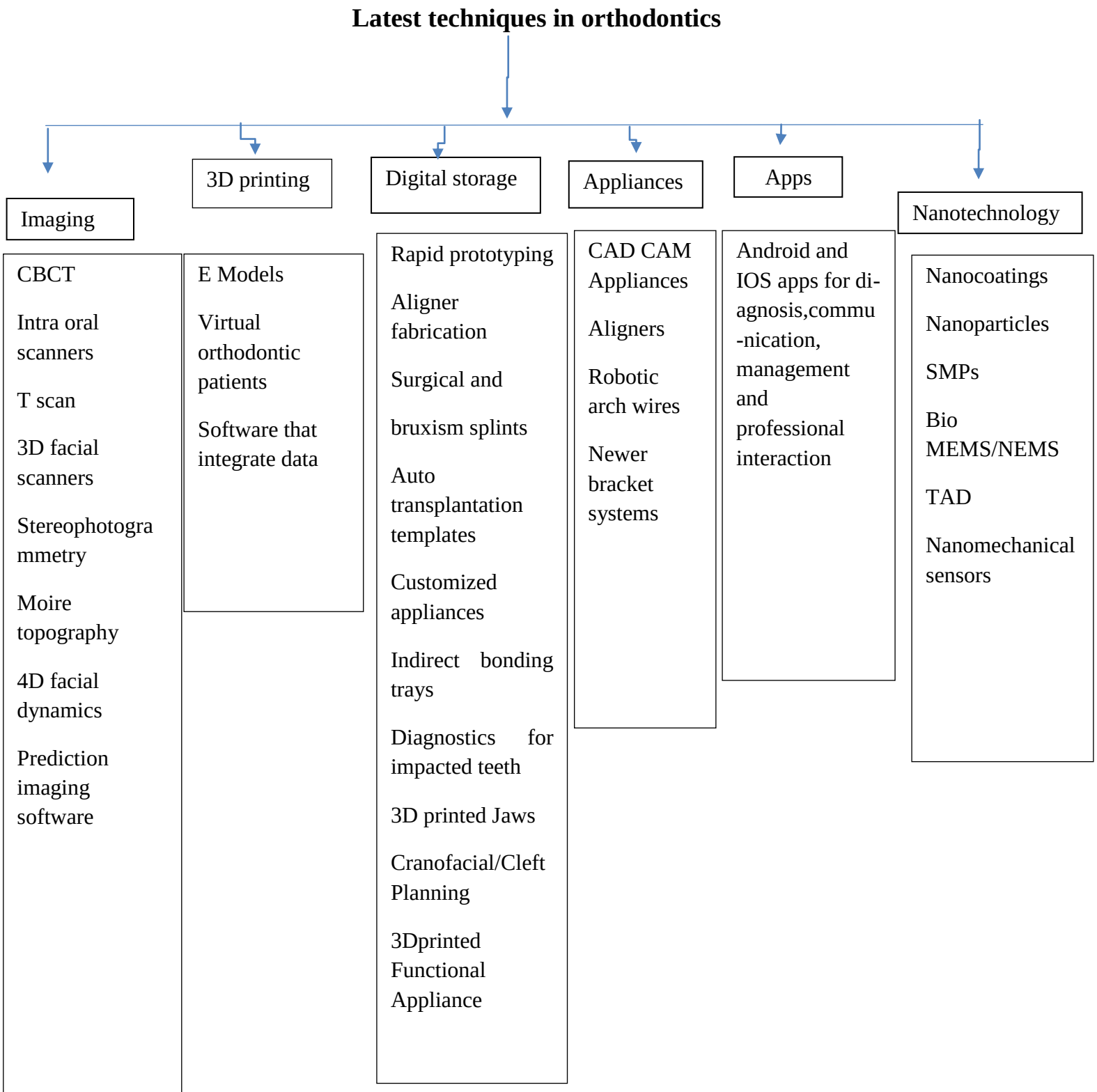
The applications of 3D imaging in orthodontics include pretreatment diagnosis and treatment planning and post-orthodontic assessment of dentoskeletal relationships and facial aesthetics. Three-dimensionally fabricated custom made arch wires, research and medicolegal purposes are also among the benefits of using 3D models in orthodontics [2].

Various digital imaging techniques like CBCT, intra oral scanners, T scan, 3D facial scanners, 3D cephalometry, Moire topography, Stereophotogrammetry, 3D facial morphometry, 4D facial dynamics, microcomputed tomography, Tuned aperture computed tomography etc are widely used nowadays. Various CAD CAM processed appliances and aligners are also available. 3D printing enables to achieve various products with high level of precision. The use of the technology to build dental models, removable appliances, customized brackets and arch wires, and occlusal splints has been attempted and reported in the orthodontic literature [1].

Rapid prototyping (RP) is a technique by which 3D models are fabricated from computer aided designs and it is built layer by layer according to the 3D input [3]. Various Android and IOS apps for management, diagnosis, communication and professional interaction are also widely used nowadays. Nanotechnology has got several applications in orthodontics and it includes mainly nanocoatings in archwires, nanoparticles in orthodontic adhesives etc. Microsensor technology to help monitor removable appliance wear is also a new invention.

Flowchart1. Shows the various latest techniques in

Orthodontics.



Flow chart 1: Latest techniques in orthodontics

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LATEST IMAGING TECHNIQUES

CBCT

CBCT was introduced in dental radiology in 1998 with the NewTom QR-DVT 9,000 (NIM, s.r.l., Verona, Italy) [4]. During a CBCT scan, many single 2D snapshot images are captured from predefined angles as the machine moves through a single iso centric rotation of the x-ray source/sensor unit.

Advantages of CBCT over 2D imaging techniques are [5];

- 3D representation of dental and craniofacial structures.
- Magnification errors or projection artifacts are avoided.
- Management of superimpositions
- Interoperability in Digital Imaging and Communications in Medicine (DICOM) format
- Generated data can be used for diagnosis, modeling, and manufacturing of appliances.
- Radiation exposure magnitude lower than that of medical CT devices.

Applications of CBCT in orthodontics

- 3D lateral cephalograms
- 3D frontal cephalograms
- Volumetric 3D skeletal views to visualize maxillomandibular relationships
- Comprehensive view of dentition
- Evaluation of root resorption
- Evaluation of radiopaque bony lesions
- Evaluation of alveolar bone volume for placement of TADs
- Evaluation of TMJ
- Assessment of sinuses and airway
- 3D superimposition
- Imaging modality for CLCP patients

Advantages of 2D and 3D lateral cephalograms retrieved from CBCT images [5];

- CBCT projection magnification can be computationally corrected during primary reconstruction, helps to create an orthogonal image.
- When a standard of known length is placed in view, the CBCT lateral cephalogram can be calibrated to a true 1:1 representation of the structure being imaged.
- Ability to correct head position errors using the 3-D manipulations.
- Alignment of the cranial base between left and right sides often reveals maxillomandibular asymmetries that would be otherwise difficult to detect.
- If asymmetry exists between right and left side, it is possible to generate a lateral cephalometric view of each side for independent analysis.
- Optimal visualization of soft and hard tissues is possible.

Advantages of CBCT-generated frontal cephalograms [5];

- Volume operations enable to avoid superimposition of irrelevant structures.
- Head can be repositioned into an ideal position in all 3 planes of space before generation of a PA cephalogram.

Digital scanning in orthodontics

3D scanning of the dental arch was first introduced approximately 30 years ago for use with computer-aided design and computer-aided manufacturing (CAD/ CAM) technology in order to provide dental restorations (Mo¨rmann et al., 1985) [6].

Applications of Digital scanning in orthodontics:

- Treatment planning
- Indirect bonding tray fabrication
- Customized appliance design and construction
- Clear aligner technology
- Orthognathic surgery simulation and wafer construction

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- The scoring of surgical outcomes in patients with Cleft Lip and Palate abnormalities

Advantages of Digital scanning:

- Replaces the need for unpleasant impressions
- Accurate digital models
- Permanent digital storage of the records
- Reduces the risk of allergy to any constituents of impression materials
- More acceptable to the patients
- Reduces the traditional workflow
- Reduce the number of patients' visits
- Maximize the efficiency and cost savings in the orthodontic office .
- Patient information can be easily sent to laboratories.
- Lost or broken appliances can be easily refabricated using the digital information from database in the Cloud.

Benchtop scanners

Benchtop scanners (Figure 1) are mainly used for 3D scanning of plaster models and impressions in the laboratory. There are various scanners available commercially.

Some of them are:

- 3Shape R Series
- AGE solutions maestro 3D dental scanner
- Dental Wings scan and design systems
- Ortho Insight 3D Desktop Scanning System

Figure 1: Benchtop Scanner

Intraoral scanners

The concept of intraoral scanning in dentistry was first introduced in 1973 (Duret, 1973) [7]. A few years later, a chair-side scanning device utilising CAD/CAM technology was available commercially and manufactured by Sirona Dental Systems (CEREC) (Brandestini and Moermann, 1989; Mo¨rmann, 2006[8]. This led to introduction of the first orthodontic scanning system; OrthoCAD, developed by Cadent in 1999.

The various intraoral scanners available commercially are:

- The TRIOSH Intraoral scanner marketed by 3Shape
- The LythosTM intraoral scanner marketed by Ormco
- The True Definition scanner marketed by 3M ESPE
- iTeroH intraoral scanner marketed by Align Technology Inc.
- PlanScanH marketed by Planmeca (Figure 2)

Figure 2: Intraoral scanner

T- scan

T-scan is a digital occlusal technology that records in real-time, quantifiable relative occlusal force, and contact time sequencing. T-scan system is comprised of a USB handle, a processing unit, the U-shaped HD sensor of large and small sizes, and color monitor of the computer screen with T-Scan® software [9].

The T-Scan® III system records and displays for visual interpretation the occlusal contact sequence, individual tooth contact force percentages, the bilateral (right-left) force distribution, and the percentage of occlusal force present in anterior and posterior quadrants.

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PARTS OF T-SCAN

- Sensor and support

  a. large b. small
- Handle assembly (Figure 3)
- Computer software
- Printer

Figure 3: T-scan handle

Applications of T-scan in orthodontics:

- Document occlusion prior to treatment and track changes in the bite over time
- Identify lateral interferences
- Recognize early and high forces so we can quickly redistribute them
- Verify proper occlusion, both aesthetically and functionally
- Prevent patients from developing malocclusion later in life
- Ensure long-lasting, stable results

3D facial scanners

Facial scanners help to acquire three-dimensional topography of the facial surface anatomy, automatic facial landmark recognition, and analysis of the symmetry and proportions of the face. Practical applications of facial scanners are quantitative and qualitative assessment of growth and development, ethnic variations, gender differences, and isolation of specific diagnostic traits in selected populations of patients with craniofacial anomalies [2,10].

Stereophotogrammetry

Stereophotogrammetry is a unique method which utilizes means of triangulation and camera pairs in stereo configuration to recover the 3D distance to features on the facial surface [1]. Burke and Beard introduced the concept in 1967 [11].

Advantages of 3D photogrammetry:

- A near-instantaneous image capture (on the order of 1.5 milliseconds)
- Reduces motion artefacts and makes it suitable for children, even babies.
- Image quality can be immediately reviewed
- Software tools are available to view and manipulate the image
- Facilitate landmark identification
- It can calculate anthropometric linear, angular, and volumetric measurements.

Disadvantages of 3D photogrammetry:

- Expensive
- Limited availability
- Shiny, shadowed, or transparent facial structures are difficult to record
- Lack of ability to calculate interactive landmarks

Moiré topography

It is a totally non-invasive, non-contact and vision-based imaging system. Moiré topography delivers 3D information based on the contour fringes and fringe intervals [2]. The depth of the fringes is obtained by ray optics and high accuracy is achieved with crude instrumentation. If a surface has sharp features, difficulty in recording is encountered. Better results can be obtained on smoothly contoured faces.

DIGITAL STORAGE

With digital impression techniques, it's easier to make digital study models. Digital storage, retrieval and transport can all be achieved through electronic systems, thus reducing vast physical storage requirements, missing and broken models, difficulty in storing large amount study models and transportation issues, which may be significant for

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audit and research. The quick online transfer of study models to laboratories for appliance construction is extremely useful in eliminating transport costs and increasing efficiency for several practices [8].

Virtual orthodontic patient

With the utilization of 3D imaging and 4D facial dynamics, it is possible to make a virtual orthodontic patient where we can see the bone, flesh and teeth in three dimensions. The concept of virtual orthodontic patient will allow considerable data to be collected and a variety of soft and hard tissue analyses to be performed. Knowledge about the masticatory system will increase, and our understanding of tooth movement biomechanics, orthopedic and orthognathic corrections will be improved [12].

OrthoCAD™ Technology

OrthoCAD™ software was developed by CADENT, Inc. (Computer Aided DENTistry, Fairview, NJ, USA) to helps the orthodontist to view, manipulate, measure and analyze 3D digital study models very easily and quickly [12]. Alginate impressions of the upper and lower dentitions, along with a bite registration are needed for the devolopment of 3D digital study models, which may be then downloaded manually or automatically from the worldwide website using OrthoCAD Downloader. The software has several diagnostic tools such as: measurement analyses (e.g. Bolton analysis); midline analysis and overbite and overjet analyses.

OrthoCAD™ software features a program called 'Occlusogram' which permit the orthodontist to visually assess the inter-occlusal contacts. OrthoCAD Virtual Set-up and OrthoCAD™ Bracket Placement System are two other interesting features of the software.

Prediction imaging software

Outcomes of orthognathic surgery can be predicted by using various available prediction software programs, alone or in combination with video images.

At present, several software systems are available which allow clinicians to manipulate digital hard and soft tissue profile tracings and subsequently morph the pretreatment image to produce a treatment simulation [13].

Quick Ceph was the first commercially available software for orthognathic surgery prediction. It permits a wide range of functions based on a 28-point digitization. When orthodontic and surgical movements are simulated, horizontal and vertical changes are recorded by the computer. An adjustment in the soft tissue occurs automatically according to predetermined ratios. Its latest version (Quick Ceph2000) incorporated many advantages, including capture and storage of high resolution images, treatment simulations, growth forecasts, compatibility with any operating system and digital image enhancement of tracing accuracy [14].

The dentofacial planner developed by Dentofacial Software Inc. (Toronto, Canada) is able to perform a variety of cephalometric analyses including Steiner, Downs, McNamara, Ricketts, Grummons, Harvold, Legan, and Jarabak. It is also able to perform CO–CR conversions, to estimate facial growth, simulate any combination of orthognathic surgery procedures including one piece or segmental maxillary surgery, mandibular advancement or setback, total or anterior mandibular sub apical surgery and chin surgery [15,16].

Vistadent (GAC International, Birmingham, AL) developed by GAC TechnoCenter is another orthognathic surgical program that uses VTO (Ricketts) for treatment simulations. It is compatible with all digital X-ray systems and digital cameras. Orthodontic treatment planner (OTP) (Pacific Coast Software, Inc., Wayzata, MN) is a surgical prediction program distributed by ortho–vision technologies [13].

Orthognathic prediction analysis (OPAL) is software that enables simulation of surgical jaw movements and dental decompensation and illustrates these changes in terms of quantitative values [17].

Dolphin imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA) is a popular software orthognathic surgical program, presently commercially available. The software indirectly digitizes dental, skeletal and soft tissue landmarks of the scanned cephalogram, using a mouse-controlled cursor. The software links up the points to give a trace image, which can be manually manipulated for improved fit. The user can then select the analysis of choice [18].

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Three-dimensional prediction methods are also available nowadays, such as surface scan/cone-beam CT, three-dimensional computerized tomography (3DCT), 3D magnetic resonance imaging (3DMRI).

3D PRINTING

Additive manufacturing or 3D printing was founded in 1990 by Wilfried Vancraen, CEO and Director of Materialise NV, the first Rapid Prototyping sector company in the Benelux region [19]. 3D printing technology helps to "print" 3D objects, prototypes, and production parts from a virtual model.

Rapid prototyping

Rapid prototyping (RP) is the fabrication of a three-dimensional (3D) model from a computer aided design (CAD), traditionally built layer by layer consistent with the 3D input [20]. The first commercial process of RP was presented at the Autofact show in Detroit (US) in November 1987 by a company called 3D systems, Inc [21].The main idea of this method is named as "layered manufacturing" or "solid free form fabrication" in which a solid 3D CAD model of an object is developed first and then it is decomposed into the cross-sectional layers and then numerical files in the form of virtual trajectories. It guides the material additive processes for physically rapid buildup of those layers in an automated fabrication machine to form the object called the prototype [22].

Types of Rapid Prototyping:

1. Stereolithography
2. Fused deposition modeling
3. Selective laser melting and selective laser sintering
4. Inkjet printing
5. Electron beam melting (EBM)
6. Digital Light Processing (DLP)
7. Laminated object manufacturing (LOM)

LATEST UPDATES IN APPLIANCES USED IN ORTHODONTICS

Align® Technology

Align® Technology, Inc. developed the Invisalign appliance for orthodontic tooth movement in the USA in 1998. It is a process in which thin, clear, overlay sequential appliances are used to straighten teeth into a perfect occlusion [12].

The process begins with the orthodontist making an initial diagnosis and treatment plan. Then the diagnosis and treatment plan along with patient's radiographs, impressions and an occlusal bite registration are sent to Align® Technology. Using the acquired data, models are converted into 3D data through 'destructive scanning' machines. A 3D model is developed from the 3D data. The treatment is divided into a series of stages that go from the present condition to the desired final result. The orthodontist will approve the simulation of the stages, following which a series of dental models are constructed from photosensitive thermoplastic. These are used to fabricate the finished product: a series of clear Invisalign aligners. The patient is instructed to wear each aligner for about 1–2 weeks, and then to move forward to the subsequent stage.

Drawbacks of Align technology:

- Orthopedic changes are not possible with this system
- Continued eruption of teeth or significant arch changes during growth does not happen during Invisalign treatment.
- Any change in tooth morphology during the treatment phase by means of restorations or composite build-ups can prevent the use of subsequent aligners.
- Root positioning at the end of the treatment is not taken into account.

Newer Bracket System

Brackets are the vehicle through which orthodontic force is transmitted to the teeth. Conventional metal brackets are always superior in its performance but in aesthetic point of view they are inferior. Because of increasing aesthetic concern among people, brackets are being made from tooth colored materials like ceramic and plastics.

Ceramic brackets

Polycrystalline and single-crystal alumina brackets are commercially available.

Advantages of ceramic brackets:

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- Excellent aesthetics
- Minimal water absorptivity
- Better mechanical properties
- Biocompatibility

Drawbacks of ceramic brackets:

- Bracket wing fracture when tying the ligature
- Fracture from archwire forces
- Tooth wear during treatment
- Enamel fracture at debonding

Plastic Brackets

Plastic brackets are made up of polycarbonate and are aesthetically appealing for the patients.

Drawbacks of plastic brackets

- Problems with torque capacity
- Excessive creep deformation
- Decreased hardness and wear resistance
- Intraoral softening
- Fracture
- Discolouration

Self-ligating brackets

Self-ligating brackets are bracket systems that have a mechanical device built into the bracket to close the edgewise slot. The cap inbuilt in the bracket holds the arch wire in the bracket slot and replaces the steel/elastomeric ligature. With the self-ligating brackets, the moveable fourth wall of the bracket is used to convert the slot into a tube [23].

The philosophy behind this system is to deliver light forces on a low-friction basis, thus insuring more physiologic tooth movement and at balanced oral interplay [23].

There are two types of self-ligating bracket systems, active and passive. They refer to the mode by which they interact with the arch wire. The active self-ligating brackets has a spring clip that encroaches on the bracket slot from the labial/buccal aspect and presses against the arch wire. It provides an active seating force on the arch wire. Examples are In-Ovation (GAC International, Bohemia, NY, USA), SPEED (Strite Industries, Cambridge, Ontario, Canada), and Time brackets (Adenta, Gilching/Munich, Germany).

The passive type self-ligating brackets use a rigid door or latch to entrap the archwire providing more room for the arch wire and the clip does not press against the archwire. Examples are Damon (Ormco/"A"Company), SmartClip™ (3M Unitek, USA), and Oyster ESL (Gestenco International, Gothenburg, Sweden)[23].

Benefits of self-ligating brackets:

- Reduced friction between arch wire and bracket
- Reduced clinical forces
- Reduced treatment time
- Faster alignment
- Faster space closure
- Different arch dimensions
- Better alignment and occlusal outcomes
- Less patient pain
- More hygienic.
- Less associated subjective discomfort
- Promotion of periodontal health
- Superior torque expression

APPS USED IN ORTHODONTICS

Software application abbreviated as Apps are also developed in orthodontics. Various IOS and Android applications are developed for diagnosis, treatment planning, communication and interaction with patients. The applications range from clinician's apps for practice management, apps for patients like diagnostic apps, patient reminder apps, progress trackers, public awareness information, and orthodontic educational apps like peer reviewed journals, model analysis apps etc [24].

Table 1: shows various examples of Apps used in Orthodontics.

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Clinicians Apps	Patients Apps	Educational Apps
Orthodontic update (provides access to the publications)	**Bracemate** (provides emergency informations to follow if there is any problem, patient can pick colours of the modules they wanted for their teeth)	**Glossary of orthodontic terms** (dictionary app for students to clear concepts of all the terms used in orthodontics)
Doctor smile orthodontics (for giving patient education and motivation)	**Brace reminder** (notification reminder for tightening)	**AJODO**(Abstracts of articles can be read)
Dolphin MyOrthodontist (helps to connect with the patients, appointments, account balances, media for patient education can be managed)	**My orthodontist** (provides information about orthodontist, FAQs, office hours, directions)	**Oneceph** (for cephalometric analysis)
Dental monitoring (Allows remote monitoring of a patient, educate the patient to take good picture of the teeth.)	**Orthodontic guide** (provides information about orthodontic speciality and treatment options)	**iModel Analysis** (for study model analysis)
REM orthodontics (for shopping of orthodontic matierals)	**Trayminder aligner tracker**(helps the patient to track aligner wear time on each day, get a reminder to switch to the next aligner, takes teeth selfies to document progress.)	**Interceptive orthodontics** (provides step by step guide to early intervention in cases of ectopic eruption of maxillary canines and molars)

Table 1: Examples of various Apps used in orthodontics

NANOTECHNOLOGY IN ORTHODONTICS

The term "Nano" means "dwarf" in Greek. A nanometer is one billionth of a meter or 10^9[19]. Nanotechnology has got several applications in medicine, dentistry as well as in orthodontics.

Various applications of nanotechnology in orthodontics include [25];

- *Nanocoatings in archwires* – Nanoparticles acts as dry lubricants and helps to minimize the frictional forces between the orthodontic wire and brackets. Inorganic fullerene-like nanoparticles of tungsten sulflide (IF-WS2), have been used as self- lubricating coatings for orthodontic stainless steel wires.
- *Nanoparticle in Orthodontic adhesive*- Polymer nanocomposites contain silica nano fillers that are 0.005- 0.01 microns in size. Due to the reduced dimension of the particles and a wide size distribution, an increased filler load can be achieved that reduces polymerization shrinkage and also increases mechanical properties such as tensile and compressive strength and resistance to fracture.
- *Nanoparticle delivery from elastomeric ligature*- Elastomeric ligatures deliver nanoparticles that can be anticariogenic (fluoride), antiinflammatory and antibiotic drug molecules embedded in the elastomeric matrix.
- *Shape memory polymers in orthodontics*- Shape memory nanocomposite polymers can produce esthetic orthodontic wires that have the property of shape memory also. The SMP materials are clear, colourable, and stain resistant, providing the patient a more aesthetically appealing appliance during treatment
- *Control of oral Biofilms during orthodontic treatment*- Metal nanoparticles in the size range of 1-10 nm have biocidal activity against bacteria. So combining dental materials with NPs or coating surfaces with NPs helps to prevent microbial adhesion, with the aim of reducing biofilm formation. Resin composites containing silver ion-implanted fillers that release silver ions have been found to have antibacterial effects on oral streptococci [26]. Nitrogen doped Titanium dioxide (TiO2), Silver (Ag), Gold (Au) ,

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Silica (SiO2) Copper (Cu/CuO) and ZnO nanoparticles are used as antimicrobial agents.

- *Smart brackets with nanomechanical sensors*- Nanomechanical sensors can be fabricated and be incorporated into the base of orthodontic brackets which will provide the information about the force level applied by the bracket on the tooth. Nano chip encapsulated into small low profile contemporary bracket systems can be used.
- *Temporary anchorage devices with nanocoatings*- Biocompatible coatings like Titanium nanotubes can enhance initial osseointegration and can serve as an interfacial layer between the newly formed bone and the TAD.

Microsensor technology

Microsensor technology to help monitor removable appliance wear is also a new invention. It is comprised of a miniature microprocessor with size smaller than a coin which is embedded into the removable appliance. It is wirelessly connected to a software which will calculate the real time wear of the appliance by the patient. It will help to assess the patient's compliance towards the treatment. Examples for few microsensors monitoring removable appliance wear are TheraMon-microsensor [27] (Handelsagentur Gschladt, Hargelsberg, Austria) and Smart retainer environmental microsensor [28] (Atlanta, Ga).

CONCLUSION

The past few decades have witnessed the great leap of orthodontics into digital technology. The digital era has helped orthodontists to work efficiently and save manpower a lot. Every day newer technologies are being discovered and are helping the clinician for better understanding of patient's problems, diagnosis, treatment planning and execution of the plan for more precise results.

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