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ROLE OF 3D PRINTING CATCHING UP WITH EXPECTATIONS IN PAEDIATRIC DENTISTRY.

3D PRINTING IN DENTISTRY

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ROLE OF 3D PRINTING - CATCHING UP WITH EXPECTATIONS IN PAEDIATRIC DENTISTRY

ABSTRACT:

The rise of three-dimensional printing has changed the face of dentistry over the past decade. 3D printing is a versatile technique which allows the fabrication of fully automated and tailor-made treatment plans, thereby delivering customized dental devices to the patients. It is highly efficient, reproducible, and provides accurate results in an affordable manner. Apart from its clinical success, 3D printing techniques are employed in developing precise models for dental education, including patient awareness. This essay describes the evolution and current trends in 3D printing applications among various areas of Paediatric dentistry. The aim is to focus on the process of the 3D printing used in the clinical diagnosis of different dental conditions and how they can be applied in Paediatric dentistry. A brief outlook on the most recent manufacturing techniques of 3D printed objects and their current and future implications are also discussed.

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PAPEL DE LA IMPRESIÓN 3D: PONERSE AL DÍA CON LAS EXPECTATIVAS EN ODONTOLOGÍA PEDIÁTRICA

RESUMEN

El auge de la impresión tridimensional ha cambiado la cara de la odontología en la última década. La impresión 3D es una técnica versátil que permite la fabricación de planes de tratamiento totalmente automatizados y a medida, ofreciendo así dispositivos dentales personalizados a los pacientes. Es muy eficaz, reproducible y proporciona resultados precisos de forma asequible. Aparte de su éxito clínico, las técnicas de impresión 3D se emplean en el desarrollo de modelos precisos para la educación dental, incluida la sensibilización de los pacientes. Este ensayo describe la evolución y las tendencias actuales de las aplicaciones de la impresión 3D en diversas áreas de la odontología pediátrica. El objetivo es centrarse en el proceso de la impresión 3D utilizado en el diagnóstico clínico de diferentes afecciones dentales y cómo pueden aplicarse en la odontología pediátrica. También se discute una breve perspectiva sobre las técnicas más recientes de fabricación de objetos impresos en 3D y sus implicaciones actuales y futuras.

INTRODUCTION

The term 3D printing is used to describe a manufacturing method that builds objects layer by layer, adding multiple layers to form the desired object (1). This process is currently described as additive manufacturing or rapid prototyping (2). Charles was Hull The ‘founder’ of 3D printing from the University of Colorado, USA. 3D printing started in the early 1980s, using ultraviolet (UV) light to harden the surface coatings. In 1986 He filed the first patent related to one of the techniques of 3D printing called stereolithography (SL) (3).

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Table 1: A TIMELINE DEPICTING THE 3D PRINTING TECHNOLOGY EVOLUTION IN MEDICAL FIELD

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Table 1. A timeline depicting the evolution of the three-dimensional (3D) printing technologies of importance for the medical field.

Year	Key Developments
1984	Invention of stereolithography (SLA) 3D printing (Charles Hull)
1986	Invention of the selective laser sintering (SLS) process (Carl Deckard)
1988	Bioprinting by 2D micro-positioning of cells and the first commercial SLA 3D printer (Charles Hull)
1989	Patenting of a fused deposition modelling (Lisa and Scott Crump)
1999	First 3D-printed organ—a bladder—used for transplantation (Wake Forest Institute for Regenerative Medicine)
2000	EnvisionTEC launched the first commercial extrusion-based bioprinter, the 3D-Bioplotter
2002	First early stage kidney prototype bioprinted via microextrusion (Wake Forest Institute for Regenerative Medicine)
2003	First inkjet bioprinter (modified HP standard inkjet printer)
2005	Founding of RepRap, an open source initiative to build a 3D printer that can print most of its own components
2007	Selective laser sintering printer becomes available, for 3D parts fabrication from fused metal/plastic
2008	First 3D-printed prosthetic leg
2009	First 3D-printed blood vessels (Organovo)
2012	First 3D-printed jaw
2014	First 3D-printed human liver tissue (Organovo), and first desk-top bioprinter (Allevi)
2015	First implanted 3D-printed bioresorbable scaffold for periodontal repair (University of Michigan)
2018	First commercial 3D-printed full human tissue (skin) model Poieskin (Poietis)
2019	First 3D-printed heart that contracts, with blood vessels (University of Tel Aviv) and 3D-printed lung air-sac with surrounding blood vessels (Volumetric)
2020	3D printer for personalized medicine M3DIMAKER (FabRx)

Adapted from GlobalData, "The history of 3D printing", Carlos Gonzales, ASME, and [3].

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MILLING Vs ADDITIVE MANUFACTURING:

The conventional subtractive manufacturing technique also referred to as milling starts with the removal of material by drilling, grinding, boring, or cutting solid blocks or bars (4). additive manufacturing/ 3D printing is the process of adding material layer by layer to form an object often referred as 3D printing or rapid prototyping. conventional machining requires high energy, creates high wastage, lacks the flexibility of end products whereas additive manufacturing is cost-effective, improves end-product performance with less wastage (5). Conventional milling creates high wastage which can be minimized by utilizing the technique in adjunction with additive manufacturing Figure 1,2.

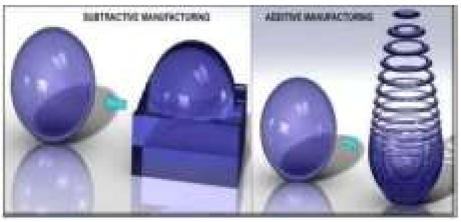

Figure 1: Milling vs Additive Manufacturing

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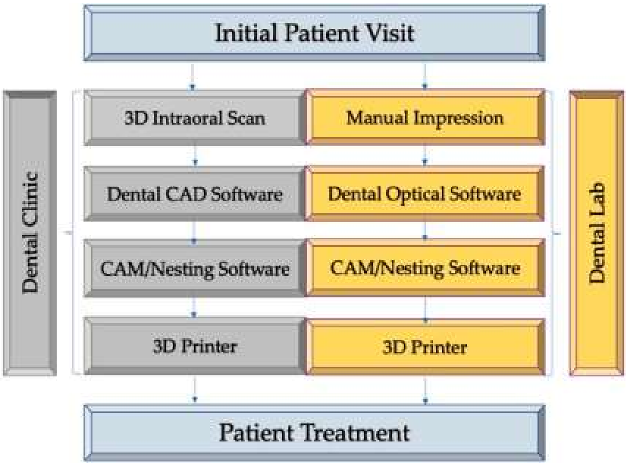

Figure 2: Digital workflow of dental diagnosis and treatment using CAD/CAM and 3D Printing technology

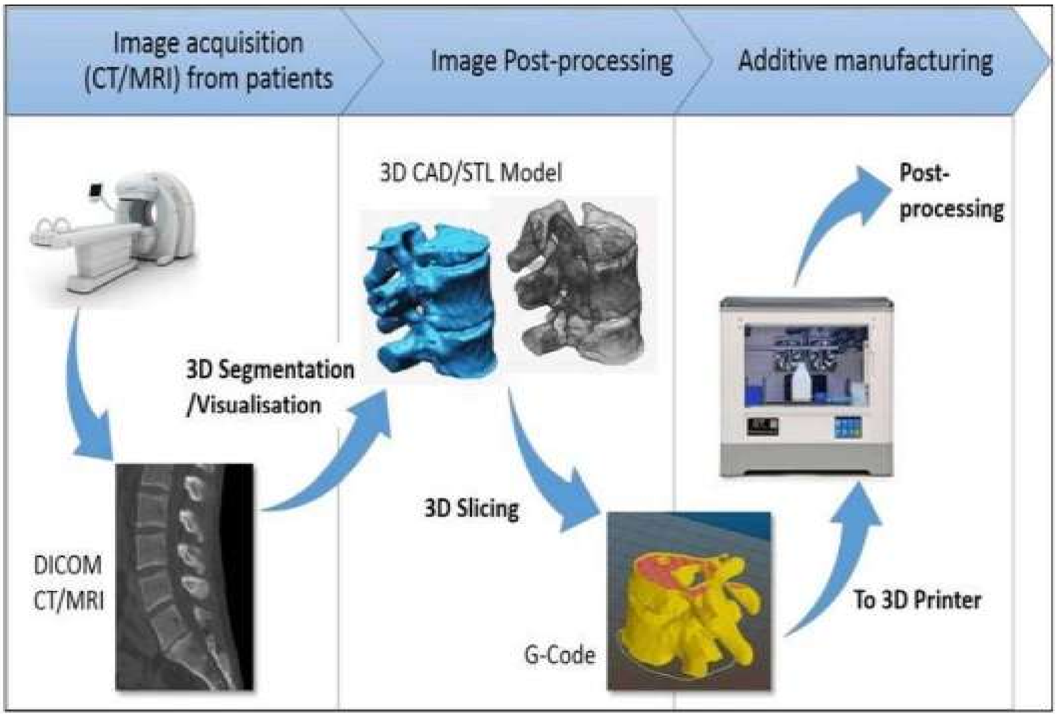

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Figure 3: Process of 3D printing

IMAGE ACQUISITION:

The first step comprises data acquisition through various scanning technologies like Computerized tomography (CT), magnetic resonance imaging (MRI), Cone Beam Computed Tomography (CBCT), and laser digitizing are the most common techniques with extraoral or intraoral scanning devices.3D formats should be converted to STL format to allow recognition by the printer's software.

1. Standard Tessellation Language

2. [STL] FILE CONVERSION:

STL is the standard file type used by most rapid prototyping systems. It is a triangulated representation of the CAD model. The software generates a tessellated File with X, Y, Z coordinates of the three vertices of each triangle, with an index to determine the orientation of the surface. Then STL file is imported into the printer software (SLICER) and processed Figure 4.

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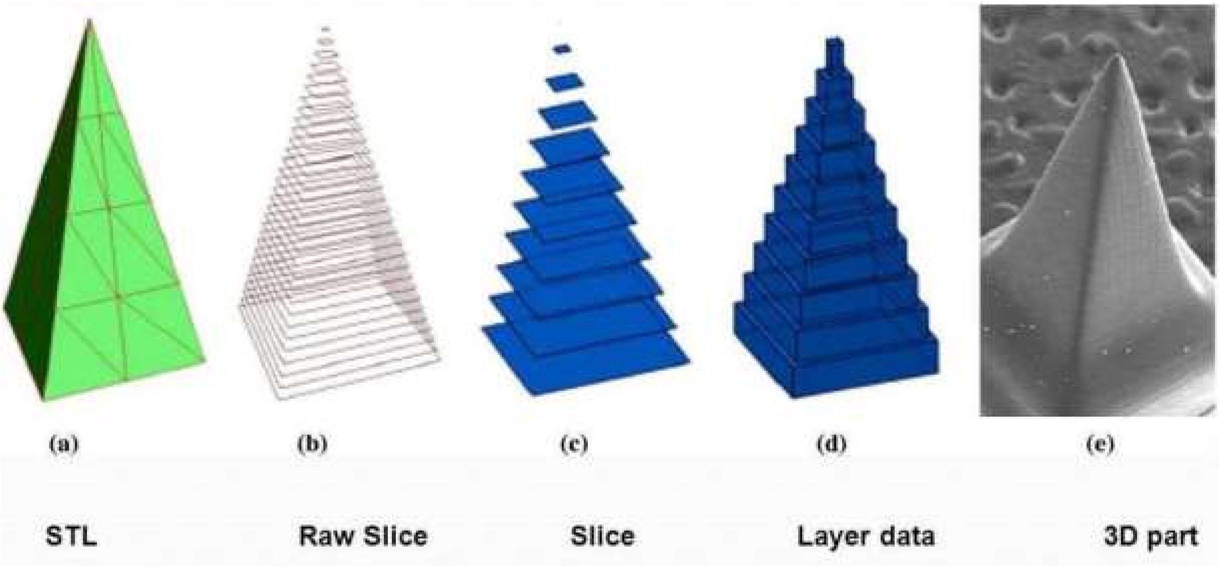

Figure 4: Slicing the STL file

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3. POST- PROCESSING:

Now the processed data is used to manufacture using computer-aided manufacturing. The 3D printer follows the G-code instructions to lay down successive layers of material to build the model from a series of cross-sections.

Primary post-processing steps include cleaning and support structure removal. However, these steps vary by technology.

Secondary post-processing includes sanding, filling, priming, painting, and finishing that improves the aesthetics and function.

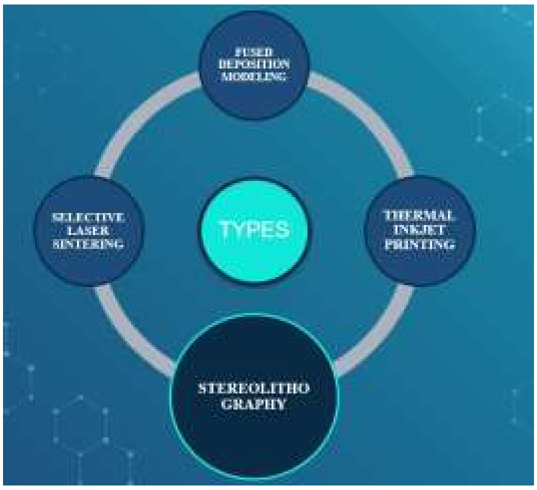

Figure 5: Classification of types of 3D printing

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1. FUSED DEPOSITION MODELLING:

FDM is one of the earliest 3D printing technologies used to produce the first medical model in 1999. An FDM printer is essentially a robotic glue gun with an extruder that traverses a stationary platform, or a platform that moves below a stationary extruder. Objects are then 'sliced' into different layers by the software and are then transferred to the printer. However, Materials must be thermoplastic by nature (6) Figure 6

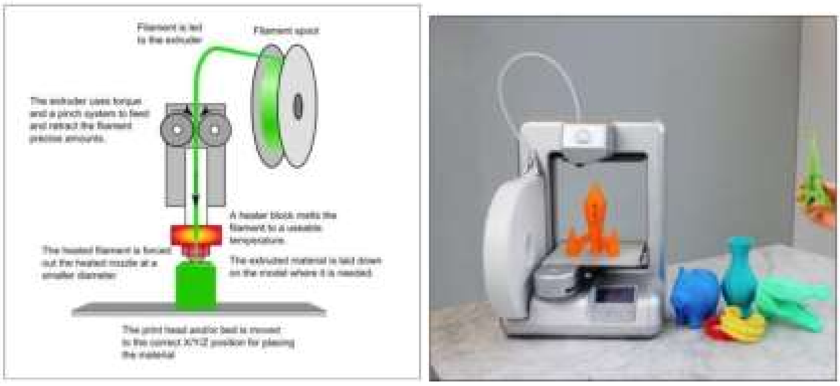

Figure 6: Fused deposition modelling (FDM)

2. STEREOLITHIOGRAPHY (SLA):

Stereolithography employs a liquid ultraviolet curable photopolymer resin and an ultraviolet laser to build parts layer by layer. A pattern on the liquid resin layer is traced by UV laser beam which cures and solidifies the pattern and joins it to the layer below. After completion of tracing, the SLA's elevator platform descends by a distance of a single layer of thickness, typically 0.05 mm to

0.15 mm (0.002" to 0.006"). Then, a resin-filled blade sweeps again, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced which is joined to the previous layer. After being built, parts are immersed in a chemical bath to clean

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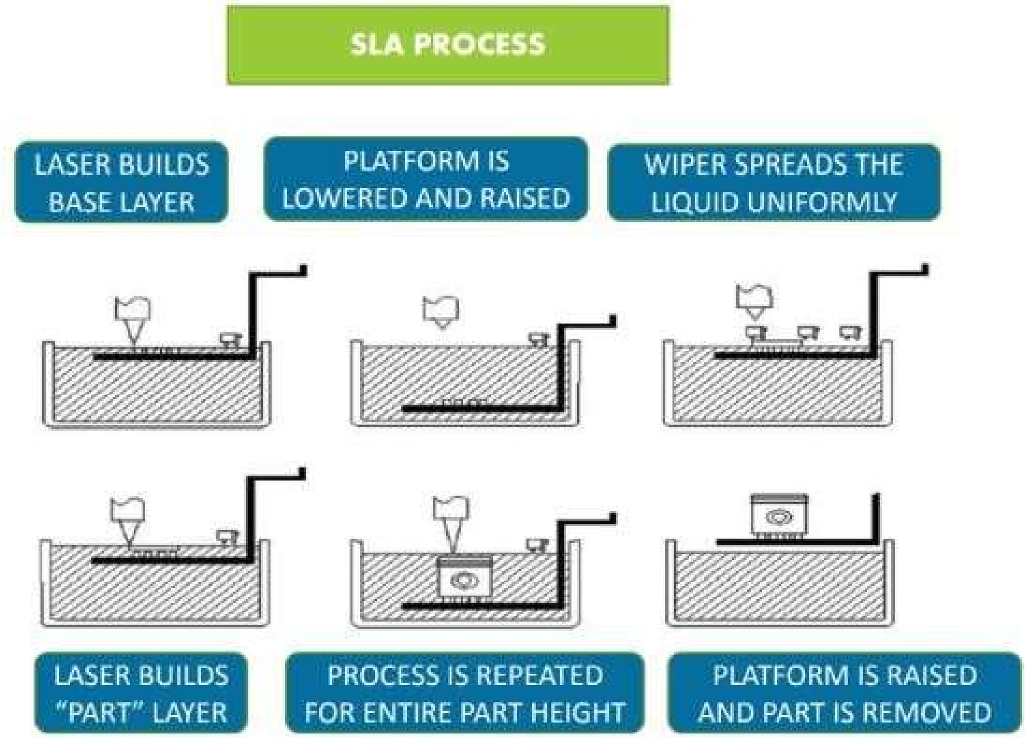
excess resin and subsequently cured in an



ultraviolet oven [Figure7] [7].

Figure 7: Stereolithography

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3. SELECTIVE LASER SINTERING[SLS]:

A scanning laser uses fine material powder, like plastic, metal, glass, ceramic to build up structures layer by layer into a desired three-dimensional shape. Initially, the powder is laid down incrementally, and a fine layer of material is evenly spread over the surface. Now the laser selectively fuses powdered material by scanning cross-sections generated from scan data. After scanning each cross-section, the powder bed is lowered by one layer thickness, and a new layer of material is applied on top of it, and the process is repeated until the 3D structure is completed Figure 8 (7).

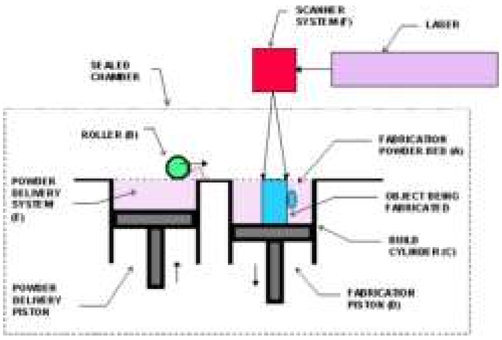

Figure 8: Selective Laser Sintering (SLS)

4. THERMAL INKJET PRINTING (TIJ):

It is a contact-free method of deposition of ink drops or other materials by heat or mechanical compression of the print head following the digital instructions. On heating, the print head small air bubbles collapse creating pressure pulses that eject droplets from the nozzle. Droplet size (10

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- 150 picolitres) can be adjusted by ink viscosity, pulse frequency, and temperature. TIJ printers are also ideal for drug delivery and gene transfection during tissue construction Figure 9 (8,9).

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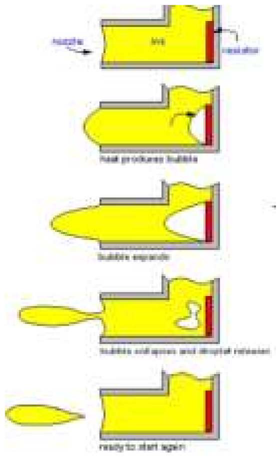

Figure 9: Thermal Inkjet Printing (TIJ)

Hydrogels are crosslinked porous polymers with hydrophilic characteristics closely resembling extracellular matrix (ECM). They have high tunability in their biological, chemical, mechanical and rheological properties, demonstrating elastic characteristics (10,11). They need to be fluid enough to eject from nozzles and be viscous enough to form structural layers. In addition to naturally derived hydrogels, synthetic hydrogels are used in 3D printing due to their controllable properties in degradation and high mechanical characteristics (12).

THERMOPLASTIC MATERIALS:

Polymer-based 3D printing accounts for the most commonly used material made from filaments that are heated as they are deposited through the nozzle, allowing the materials to be tunable for specific structures (13,14). A variety of these materials including, polypropylene (PP), acrylonitrile butadiene styrene (ABS), polyethylene (PE), polylactic acid (PLA), are considered suitable for oral cavity (13,15). More recently, thermoplastic filament materials like

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PMMA (polymethylmethacrylate), PEEK (polyether ether ketone) have been used in dental 3D printing (16).

METALS:

cobalt-chromium (CoCr), Nickel chromium, stainless steel and nickel alloys are common materials used in dentistry. CoCr alloy fabricated from 3D printing techniques has shown higher biocompatibility in the oral cavity than other materials. It is also used as alternatives to gold alloy. Ceramics, such as zirconia, CoCr represent ideal materials to form 3D dental prosthesis (17).

3D PRINTING APPLICATIONS IN PAEDIATRIC AND PREVENTIVE DENTISTRY:

3D IN PRE-SURGICAL INFANT ORTHOPAEDICS:

Nasoalveolar moulding (NAM) is an accepted presurgical treatment modality for new-borns with cleft lip and palate (CLP) to design NAM appliance. In the traditional method, this appliance is created based on the patient's maxillary cast, produced from a conventional impression challenging to manage and time-consuming and requires high – expertise (18).

3D printing technology precisely represent anatomic structures. It segments alveolar structures, bridges clefts, and generates a series of NAM device designs destined for subsequent treatment. In 3D printing, a patient's oral cavity is simulated using computer software. It marks

reference points and reference lines digitally to design the NAM appliance [Figure]. It narrows the alveolar gap by 1 mm each week by rotating the greater alveolar segment. A maxillary cast of the predicted molding stage is created using three-dimensional printing. Subsequent appliances are constructed in advance, based on a series of computer-generated models. Each patient had a total of three clinic visits spaced one month apart. Anthropometric measurements and bony segment volumes will be recorded

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using reference points and lines before and after treatment [18].

With 3D printed NAM appliance, Alveolar cleft widths get narrowed significantly, the soft-tissue volume of each segment gets expanded, and the arc of the alveolus became more contiguous across the cleft. The software generates 3D-printable series of NAM device designs. Multidisciplinary teams can discuss, share patient information and design customized Naso-alveolar Molding devices with improved efficiency. Using computer-based Naso-alveolar moulding devices allowed for better control of the force's magnitude and direction and minimize the time it takes to produce such devices [19]. In a study, split-type 3D printed presurgical Naso alveolar moulding was used for unilateral cleft palate patients to reduce the cleft gap and overall morphology of the nose [20- 21]. The accurate designs are helpful in closing complex surgical and congenital defects using obturators and prosthesis [Figure10-12].

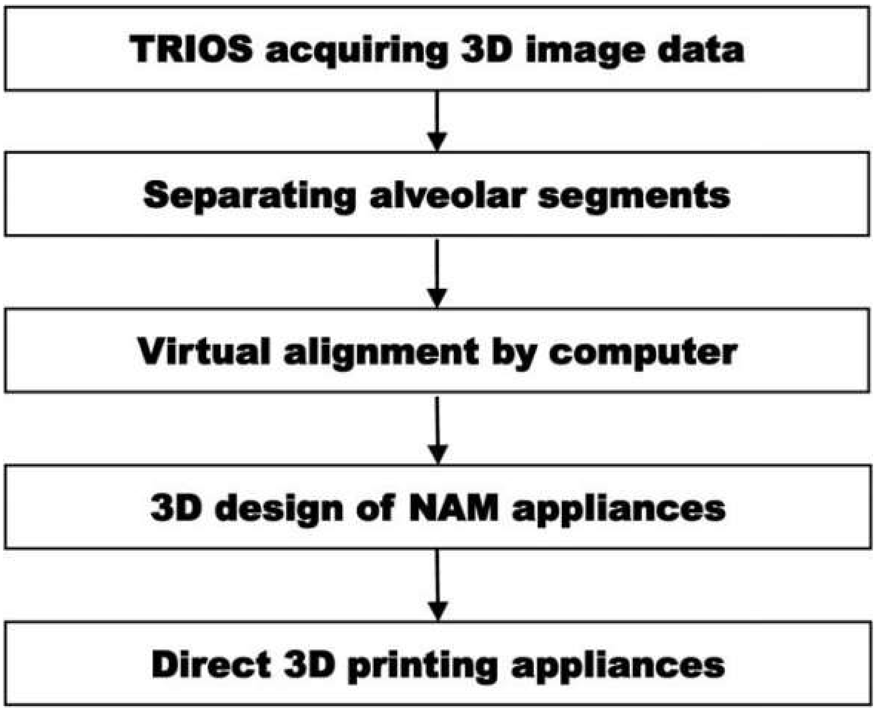

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Figure 10: 3D Printed NAM Appliance

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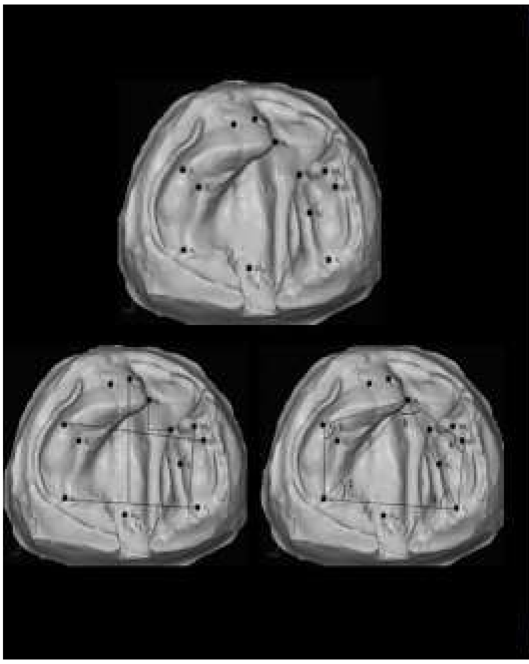

Reference point	Description
P_L	The posterior-most point of the alveolar crest in the LS
P_S	The posterior-most point of the alveolar crest in the SS
A_L	The anterior-most point of the alveolar crest in the LS
A_S	The anterior-most point of the alveolar crest in the SS
$B_{L'}$	The intersection point between the palatally extended lateral sulcus line and the gingival groove in the LS
$B_{S'}$	The intersection point between the palatally extended lateral sulcus line and the gingival groove in the SS
B_L	The intersection point between the lateral sulcus line-B_L line and the alveolar crest in the LS
B_S	The intersection point between the lateral sulcus line-B_S line and the alveolar crest in the SS
M_L	The anterior-most point of the LS from P_L-P_S line
M_S	The anterior-most point of the SS from P_L-P_S line
M_{LS}	The midpoint of the P_L-P_S line
I	The intersection point between the line from labial frenum-incisive papilla point and the alveolar crest of the premaxilla in the LS
P_L-P_S line	The horizontal reference line
S_L	The perpendicular line to the P_L-P_S line. It crosses the midpoint (M_{LS}) between P_L in the LS and P_S in the SS

LS: Larger segment, SS: Smaller segment

Figure 11: Marking reference points and reference lines

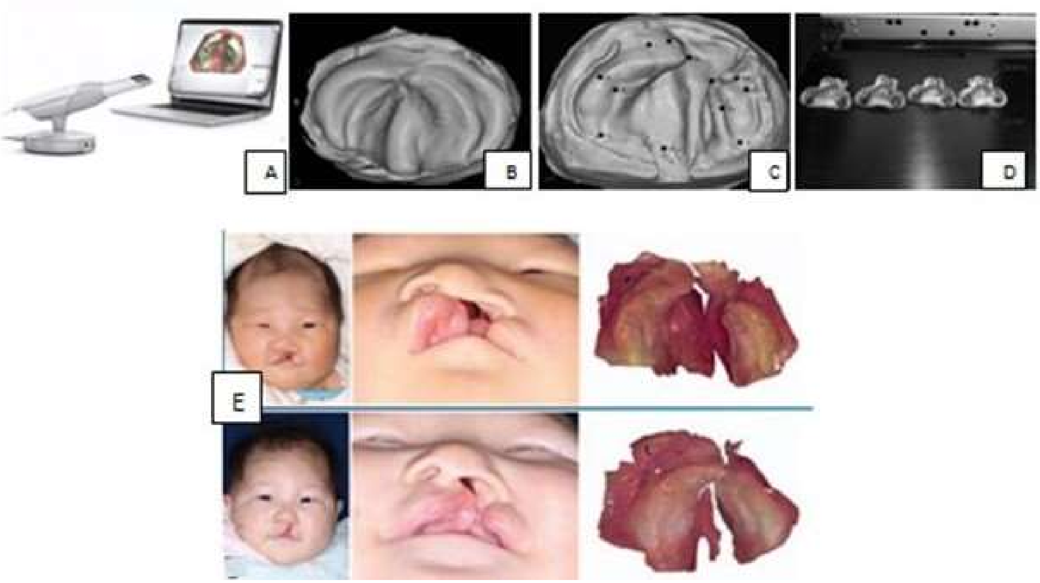

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Figure 12: A. TRIOSE 3 Shape Scanner B. The initial 3D image of maxilla C. Reference points D. Manufacturing series of NAM appliances by 3D printing E. NAM in Cleft Lip and Palate patients

RECONSTRUCTION OF CRANIOFACIAL REGION:

Craniofacial skeleton comprises of craniofacial bones and cartilages that impart specific appearance and function. 3D printing technology is ideally for bone and cartilage scaffold manufacturing by combining craniofacial geometry image and ability to print shapes with high fidelity (22).

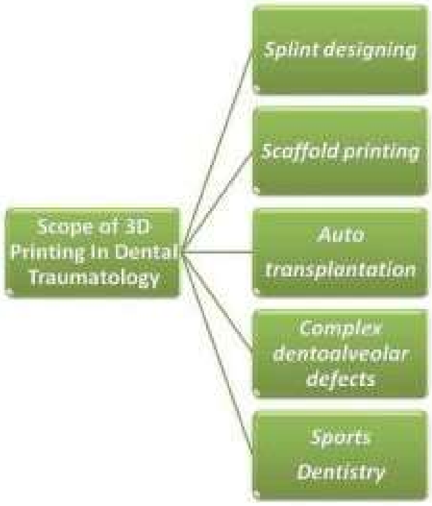

Figure 13: Scope of 3D printing in dental traumatology & sport Dentistry

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Splint designing: A custom-made splint will serve a dual purpose of securing and repositioning the traumatized teeth for desired period. In repositioning of Intruded permanent teeth Cone beam CT will enable designing of such a splint which can then be cemented or cured into its position.

3D scaffold printing in regenerative dentistry: Regenerative dentistry is an integral part of dental traumatology with modalities as revascularization and stem cell-based protocols. Use of 3D printing has already been utilized for designing and creating customized scaffolds, where stem cells can be retained and regenerated in presence of growth factors [23, 24].

Auto Transplantation: Traumatic dental injuries leading to loss of permanent tooth in early mixed dentition period precludes use of implant-based rehabilitation. Many innovative methods for auto transplantation of teeth using 3D surgical templates for guided osteotomy preparation and donor tooth placement [25].

Construction of accurate replicas for complex Dentoalveolar defects: 3-D-printed templates assist in preoperative planning for treating complex mandibular fractures and also facilitate contouring of plates [26].

Esthetic Restoration of fractured Teeth:3D printed templates provide efficient, convenient and esthetic option for the direct resin composite restoration of fractured anterior teeth. They help to reproduce the anatomy, color, and translucency of the fractured tooth with precision [27].

3D printing in Sports Dentistry: This novel technique can help in manufacturing the customized mouth guards in single appointments and keep the information stored for re-orders even at a click of a smart phone-based application. Further researches in 3D printing materials will help in creating high quality protective devices (28-30).

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FABRICATION OF DRILLING AND CUTTING GUIDES FOR TUMORS:

The use of drill guides and cutting guides allows a virtual 3D plan, created on-screen in software to be transferred to the operative site (31) Figure 14

The prostheses are prefabricated to precisely fit a pre-planned post-operative result with Precise 3D printers and high-resolution printing materials (32).

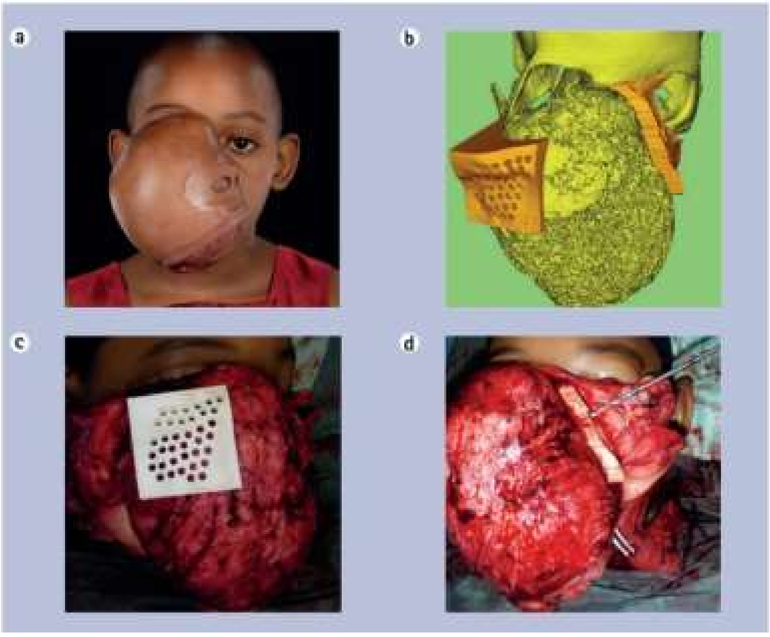

Figure 14: 3D printed guide for resection of fibrous dysplasia.

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REGENERATION OF ORAL SOFT TISSUE:

The oral mucosa loss due to trauma, infections, and tumors requires reconstruction. a volume stable 3D matrix consisting of cross-linked collagen fibers has been introduced (Geistlich Fibro- Gide). It has been shown to increase soft tissue volume [30,31]. These promising biological scaffolds decrease surgical time as well as costs.

PULP REGENERATION: Micropatterns of human dental pulp stem cells can be bio printed using fibrin base bio-ink. 3D cell printing would enable researchers to suspend and position various cells contained in hydrogels as they desire. Specifically shaped dental pulp complex was produced by 3D printing using bio thermoplastic poly caprolactone [32-34].ENDODONTIC TREATMENT IN PRIMARY AND YOUNG PERMANENT TEETH Although use of 3D printing in endodontic treatments is yet to be explored, there are several pre- clinical studies that describe the improvements brought in guided access, maneuvering obliterated pulp canals, auto transplantation, but most importantly in endodontic and general dental education [35]. Using a CAD/CAM-guided surgical template in endodontic surgery allows surgeons to target the root apex, especially in teeth with problematic anatomies [36]. Pulp necrosis, Irreversible pulpitis, or apical periodontitis can be dealt with using nonsurgical root canal treatment, which consequently relinquishes better outcomes (about 35% higher success rate) compared to the traditional techniques allowing for superior visualization, magnification and illumination [37]. The simulated root canal model has been used to get passive and active sodium hypochlorite to remove Enterococcus faecalis biofilms [38]. Although use of advanced 3D printing technology is in its budding state in endodontic surgeries, careful utilization of this tool can improve the outcome of pulp therapies in children.

ORTHODONTIC APPLIANCES: Most Paediatric dentists provide orthodontic treatment in the primary or early mixed dentition stages. The most common conditions

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treated were habits, anterior crossbite, ectopic eruption, posterior crossbite, and space maintenance (39). Detailed scans can be taken and uploaded into a software [40]. Yang (2019) customized bracket system that were made digitally through 3D printing to give patients a favorite color and shape to suit their needs, which optimized not only aesthetics but also mechanics (41). Individualized orthodontic appliances can be easily fabricated using digital models (42).

SPACE MAINTAINER: Conventional band and loop have long been used for maintaining space, but certain disadvantages such as increased chairside and laboratory time make it a cumbersome procedure. 3D-printed Space maintainer can be fabricated in precise, quick, and easy way (43). An ideal mixed dentition cast was poured of a standard dye, for a trial design of 3D-printed Space maintainer by digital scanning and designing. The cast was scanned using a 3D digital dental scanner followed by designing of band and loop similar to the conventional space maintainer. SM was printed by Micro Laser Sintering Technology which offers all benefits of an additive manufacturing process Figure 15(44).

Figure 15. 3D design of Band and Loop space maintainer

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REDUCE GAGGING – DIGITAL IMPRESSIONS AND MODELS:

Patients no longer must endure the mess and "gagging" of conventional impression taking. Intraoral digital scanning has evolved to vastly improve the world of both patient and dentist! Specific purpose made polymers is used with in-office 3D printers to 3D print accurate 3D models, improving the acceptance of child to treatment, saving time and improving the treatment efficacy of Paediatric dentist [45].

INTERIM RESTORATIONS:

A study assessed the marginal fit of 3D interim restorations with different finish lines stated that the method of crown fabrication had shown more impact than the type of finish line used [46,47]. With the 3D printed interims exhibiting lower marginal and internal gap than the milled [48].

PERIODONTAL REGENERATION:

In vivo studies that used polycaprolactone (PCL) scaffold for periodontal ligament (PDL) formation, Rasperini et al. (2015) developed the scaffold by integrating SLS technology [49]. Yin et al. (2017) prepared a digital surgical guide for rebuilding the marginal contour of gingiva using 3D printing. They designed the crowns using the Tarnow principle [50] to induce structural reformation [51-52].

The successful treatment of periodontitis includes periodontal therapy in combination with systemic antibiotic therapy [53,54]. Hence this 3D printing technology can be applied

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to treat the periodontal diseases of children precisely.

PROSTHETIC RECONSTRUCTIONS IN CHILDREN: The need for prosthesis is most commonly seen in children with abnormalities in the development of jaws and the formation of dental follicles, genetic diseases, traumas, systemic diseases (e.g., ectodermal dysplasia), rampant caries, early childhood caries, etc. Complete dentures can be customized to particular patient with 3D printing technology. Prosthetic constructions in childhood should meet both the anatomical requirements and the age related physiological and psychological features [55-65]. Dentures fabricated by 3D technique require only two appointments. However, the main limitation is lack of wax try – in. Recently virtual try in has come into play where face scan is combined with intra oral scan and teeth set up. 3D allows storage of electronic data and duplication of prosthesis in matter of hours [66-67].

IMPLANTS: Implants are indicated in Paediatric patients with ectodermal dysplasia, in patients with cleft of the alveolus and palate [68] and adolescents having anodontia, partial anodontia, congenitally missing teeth, teeth lost as a result of trauma [69].

The introduction of 3D printing allows the fabrication of precise and economical dental implants [70-71]. Materials used 3D printed dental implants are as follows [Figure 16]

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Materials Used for 3D Printing of Dental Implants
Plastic (MED690 VeroDentPlus)
Stainless Steel (Duraform 316L)
Zirconia
Titanium
Acrylic Resin
PEEK
Amorphous Magnesium Phosphate (AMP) blended with PEEK
Cobalt-Chromium (Co-Cr) Alloy

Figure 16: Materials used 3D printed dental implants

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DENTAL EDUCATIONAL MODELS: Along with increased involvement in both the chairside and laboratory setting, 3D printing and the research setting have also led to the inclusion of this technology in the education setting, both postgraduate with academies through a combined approach of research, training in dentistry, and clinical treatment [72].

FORENSIC ODONTOLOGY: 3D printing can be applied to create three dimensional replicas of the human remains from the evidence which can accurately depict all relevant information to the court and the jury, without disturbing anyone or creating bias [73]. Bite marks can provide valuable evidence to identify the criminal like in cases of child abuse [74,75]. After scanning, the entire bite mark can be recreated using 3d printing. The scans themselves digitally match the suspect's teeth using new software [76]. Thus, 3D printing can curtail the rapid loss of information that occurs in the bite marks and helps preserve maximum information [77].

PANDEMIC: **Bioprinting:** A recent technology with great potential to help fight pandemic diseases is bioprinting. This is a technology, emerged from 3D printing in 2003 [78,79] that uses bio ink as deposition material [80]. Groll [81] defined bio ink as "a cell formulation suitable for processing by an automated bio fabrication technology that contain biologically active components and biomaterials".

3D PRINTED ORAL HYGIENE AIDS: 3D printed tooth brushes allow to clean each and every tooth with multiple bristles helps in adequate cleaning of entire oral cavity in six seconds of biting and grinding in different directions.3d floss is available

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which positions floss exactly and accurately [80].

CURRENT CHALLENGES AND FUTURE PROSPECTIVES IN 3D PRINTING: 3D printing is an additive process with little material wastage, is more accurate, and can operate using various materials which are applicable to Paediatric dentistry [82]. While 3D printing allowed for innovation in several aspects, it still faces certain challenges. For example, in surgery 3D printing is paving the way to produce surgical guides; however, some of the materials used cannot be autoclavable and sterilizable, thus limiting their use [83]. In addition, accuracy is dictated by the original scan taken by intraoral scanners, which remain inaccurate when taking scans or surfaces with irregularities [84]. It increases ethical issues such as data privacy, protection, and

confidentiality,[85] It is believed that additive manufacturing will play a greater role in healthcare in Paediatric dentistry in particular in the near future.

3D VS 4D PRINTING:3D printing fabricates a static object while 4D printing allows printing of dynamic object. Advancements in printable smart materials and printing technologies will allow for 4D printing to further enhance targeted drug delivery, minimally invasive surgical treatments, soft robotics enhance cooperation of the child and other unthought of fields in Paediatric Dentistry [86].

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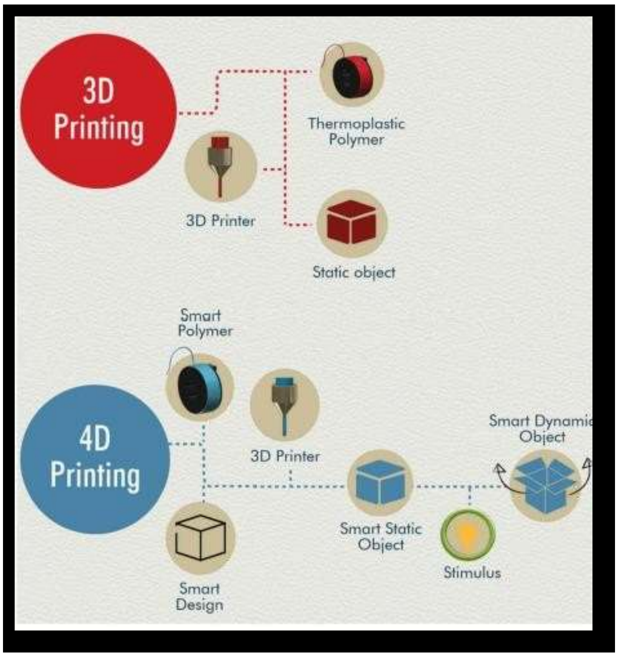

Fig 17: Illustration outlining the difference between 3D and 4D printing

SUMMARY AND CONCLUSION:

Today, a dentist's main challenge will be shifting manual to a digital workflow and integrating these new technologies and equipment into their routine practice. These tools will allow the dentist to be more creative and perform more predictable, cost-effective treatments. The benefits include simplification, minimal invasiveness, greater accuracy, a reduction in operating times, and improvement in patient comfort and aesthetics. 3D printing can be successfully utilized in highly uncooperative child, kid with special needs and with gag reflex. With this current technology treatment can be made patient friendly, healthy and short. However, with the addition of a new technology adds us a new responsibility. New standards using the equipment must ensure that the patient's

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standard of care, health and safety are not compromised.

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