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Review Article

Advances In Medical And Dental Practice: Shift From 3d To 5d Prinitng: A Review

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ABSTRACT:
This review paper focuses on the current applications of 3D, 4D and 5D printing in medical and dental practice. 3D printing is an additive layering process which functions in three axes i.e. x, y and z. This process is time consuming which imparts negative effect on this technology. These drawbacks of 3D printing can be overcome by 4D printing. 4D printing involves addition of 4th dimension, time and uses smarter printing materials to print the object faster and thus saving 90% of time and material. Printing curved surface objects with 3D and 4D technologypresented a great challenge which was overcomed by 5D printing. 5D printing adds two more axes i.e. movable print head and bed which manufactures stronger and smarter printed objects.
Key Words: 3D Printing, 4D Printing, 5D Printing.

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INTRODUCTION

In a new era of innovative development, the medical device industry is undergoing transformative changes driven by the emergence of 5D printing technologies. These advancements enable the creation of objects with unparallel complexity, durability, and precision, surpassing what is achievable with traditional advanced 3D printing techniques. For instance, in healthcare, 5D printing has opened up new possibilities in areas such as material science, drug delivery systems, and biomedical research, expanding far beyond the previous focus on designing prosthetics. The concept of 4D printing was first introduced in 2014, and by the year 2016, American universities had pioneered the idea of 5D printing.[1]

3D printing has established itself as a transformative digital technology in medical field, allowing for the rapid and automatic creation of 3D models using additive manufacturing. This technique involves building objects layer by layer, which has revolutionized the field through its integration with CAD/CAM technology.4D printing expands on 3D printing by incorporating smart materials that can change shape or function over time when exposed to external stimuli like temperature or light. This adds a chronological plane to the manufacturing process, allowing for the creation of objects that can adapt to their environment.5D printing, a further advancement, introduces two additional axes of movement, enabling the creation of curved layers rather than flat ones. This results in stronger, more intricate designs, particularly beneficial in dentistry for producing robust implants and other prosthesis.[2]

The medical and dental fields have always been at the forefront of adopting new technologies to improve patient outcomes, and the advent of 3D, 4D, and 5D printing technologies represents a significant leap forward. These innovations are not just enhancing the precision and customization of medical treatments but are also redefining what is possible in patient care, from personalized implants to bioengineered tissues.

3D PRINTING IN MEDICINE AND DENTISTRY

Stages involved in the design and production of 3d printed object

The design and production of 3D printed objects in medicine and dentistry involve four key stages:

1. **Creation of a 3D Computer- aided design (CAD) Model**: This stage begins with developing a virtual design using CAD software. The design is based on a 3D model obtained from the patient through scanning or digital imaging, which is then exported in formats like DICOM or OBJ.
2. **Generation of a Stereo lithography(STL) File**: The CAD model is converted into an STL or Virtual Reality Modelling Language (VRML) file format, which is universally recognized by 3D printers. This step translates the design into a printable form.
3. **Slicing the 3D Model**: The 3D model is processed using slicing software, dividing it into thin layers. These layers are the cross-sections that the 3D printer will use to build the object layer by layer.
4. **3D Printing and Object Creation**: The final stage involves selecting a compatible 3D printer, which reads the sliced layers and sequentially deposits material to create the final 3D object.[3]

MATERIALS INVOLVED IN DESIGN AND PRODUCTION OF 3D PRINTED OBJECT

3D printing has become increasingly prevalent in the medical and dental fields over the last decade. This technology allows for the creation of three-dimensional objects by layering materials based on a digital model. Its application in healthcare has been transformative and effective in many ways for patients.

3D printing technology utilizes a variety of materials to create fully functional parts across different industries:

1. Metals: 3D printing of aluminium, cobalt, nickel alloys, stainless steel, and titanium is key in aerospace, automotive, and medical fields for complex, high-performance parts.
2. Polymers: High-performance thermoplastics like PEEK and PMMA are used in medical devices, while PLA and ABS are common for prototypes and non-critical items.
3. Ceramics: 3D-printed ceramics are strong, durable, and fire-resistant, used in dental and aerospace applications.
4. Composites: Carbon and glass fibre-reinforced polymers offer low weight and customizable properties for high-performance uses.
5. Smart Materials: Materials like nickel-titanium and shape memory polymers change shape with stimuli, used in biomedical and micro-device applications.[4]

Its application in healthcare has been transformative and effective in many ways for patients.

USES OF 3D PRINTING IN MEDICAL FIELD

1. Personalized Implants and Prosthetics:

Custom Implants: 3D printing allows for the creation of patient-specific implants (e.g., hip joints, cranial plates) that fit perfectly, reducing the risk of complications and improving recovery times.

Prosthetics: Tailored prosthetic limbs can be printed, providing more comfort and functionality, especially for children who outgrow prosthetics quickly.

2. Surgical Planning and Education:

Anatomical Models: Surgeons can use 3D-printed models of patients' organs or tissues based on their scans (CT, MRI) to plan complex surgeries with greater precision.

Training: Medical students and professionals can practice on 3D-printed models, which replicate the texture and complexity of human tissues, leading to improved skills without risking patient safety.

3. Bioprinting and Tissue Engineering:

Bioprinting: Researchers are developing methods to print tissues and, potentially, entire organs using a patient's cells, which could eliminate organ transplant shortages and rejection risks.

4. Wound Healing: 3D-printed scaffolds are used to support tissue regeneration in wounds or burns, facilitating faster and more effective healing.
5. Drug Delivery Systems:

Custom Medication: 3D printing can produce pills with customized doses and release profiles, tailored to individual patient needs, improving treatment efficacy and adherence.[5]

USES OF 3D PRINTING IN DENTISTRY

1. Custom Dental Implants and Crowns:

Precise Fit: 3D printing allows for the production of highly accurate dental implants, crowns, bridges, and veneers that match the patient's anatomy, ensuring a better fit and more comfortable experience.

Rapid Turnaround: Traditional methods can take weeks, but 3D printing significantly reduces this time, allowing for faster treatment.

2. Orthodontics:

Invisalign and Aligners: Clear aligners are custom-made using 3D printing, offering a more aesthetic and comfortable alternative to traditional braces. This technology also allows for quicker production and easy adjustments.

3. Dental Models and Guides:

Surgical Guides: For complex procedures like implant placements, Endosurgical guides. 3D-printed guides based on a patient's scan can enhance accuracy, reducing the risk of errors.

Educational Models: Dental students can practice on realistic 3D-printed teeth and jaws, gaining hands-on experience before treating patients.

4. Restorative Dentistry:

Restoration Work: Dentures, inlays, and onlays can be 3D printed with precise materials that mimic the look and function of natural teeth, providing durable and aesthetically pleasing solutions.[6]

ADVANTAGES AND DISADVANTAGES OF 3D PRINTING

3D printing, while innovative, has limitations such as long printing times, static outputs, and material weaknesses that restrict its applications. These drawbacks include the need for post-print assembly, issues with material durability, and environmental concerns like waste generation. 4D printing addresses these challenges by using smart materials that respond to environmental stimuli (e.g., temperature, light) and can change shape or properties over time. This technology significantly reduces printing time (by 70-90%), enables self-repair and self-assembly, and expands potential applications in fields like medicine and aerospace.

4D PRINTING IN MEDICAL AND DENTISTRY

The term "4D" in the medical and dental field refers to advanced imaging technologies that go beyond traditional 3D imaging by incorporating the element of time, allowing for dynamic and real-time visualization of structures and processes within the body. This innovation is crucial for diagnostics, treatment planning, and monitoring in various medical and dental applications.

4D IN MEDICAL IMAGING

1. Cardiology: In cardiology, 4D imaging is particularly valuable for visualizing the heart's structure and function. Techniques like 4D echocardiography enable clinicians to observe the heart as it beats, providing real-time images of the heart's chambers, valves, and blood flow. This allows for more accurate assessments of cardiac function and aids in the diagnosis of conditions such as valvular heart disease, congenital heart defects, and heart failure[7].
2. Oncology: 4D imaging plays a critical role in radiation therapy for cancer treatment. By capturing images of tumors over time, clinicians can account for movements such as breathing during treatment. This ensures more precise targeting of radiation doses, minimizing damage to surrounding healthy tissues and improving treatment outcomes.
3. Obstetrics and Gynaecology: 4D ultrasound is widely used in prenatal care, allowing expecting parents and healthcare providers to see real-time, moving images of a fetus. This technology is not only valuable for bonding and reassurance but also for detecting abnormalities in fetal development, assessing amniotic fluid levels, and monitoring fetal movements and heart rates.
4. Surgical Planning and Navigation: In complex surgeries, especially in neurosurgery and orthopaedics, 4D imaging helps surgeons plan and execute procedures with greater precision. By visualizing anatomical structures as they change or move, surgeons can navigate more accurately during operations, reducing the risk of complications.
5. Plastic Surgery: Facial Reconstruction: 4D imaging allows surgeons to simulate the outcomes of facial reconstructions by visualizing how changes will impact facial expressions and muscle movements over time. This helps in planning more accurate procedures, reducing the likelihood of postoperative complications, and improving aesthetic outcomes.

Breast Surgery: For procedures like breast reconstruction or augmentation, 4D imaging can simulate how implants will behave over time, factoring in movements and changes in body position. This enhances the surgeon's ability to predict and achieve desired results.

Tissue Movement Tracking: During surgery, 4D imaging can help track the movement of soft tissues in real-time, providing surgeons with dynamic feedback and ensuring that adjustments are made accurately, leading to better functional and aesthetic outcomes.

6. Orthopedics: Joint and Bone Movement Analysis

Dynamic Joint Assessment: 4D imaging provides a detailed analysis of joint movements, which is crucial for diagnosing and treating conditions like arthritis, ligament injuries, or congenital deformities. It enables the visualization of how bones and joints move in real-time.

Pre-Surgical Planning: In procedures like joint replacements or fracture repairs, 4D imaging helps in planning the exact placement of implants or fixation devices by simulating how the bones and joints will move post-surgery. This can reduce the risk of implant misalignment and improve surgical outcomes.

Spinal Assessment: Dynamic Spinal Imaging: 4D technology is used to study spinal movements and diagnose issues like scoliosis, herniated discs, or other spinal deformities. It helps in understanding the dynamics of the spine under different conditions, which is crucial for planning corrective surgeries.

Rehabilitation and Monitoring:Gait Analysis: 4D imaging is used in the rehabilitation of orthopaedic patients by analyzing their gait in real-time. This helps in designing customized physical therapy programs and monitoring the progress of recovery, leading to more effective rehabilitation.

7. Pediatrics:Fetal and Neonatal Imaging: Congenital Anomaly Detection: 4D ultrasound is particularly valuable in pediatrics for the early detection of congenital anomalies in utero. This enables timely intervention planning, such as

surgeries that might be required immediately after birth.

Real-time Observation of Fetal Development: 4D imaging allows for the continuous monitoring of fetal development, offering insights into fetalbehaviour and movements that can help assess overall health and development.

Growth and Development Monitoring:Bone Growth Tracking: In pediatricorthopedics, 4D imaging can be used to monitor the growth and development of bones and joints over time, allowing for early detection and treatment of growth disorders or developmental abnormalities.

Respiratory and Cardiovascular Assessment: Dynamic Heart and Lung Monitoring: 4D echocardiography and other imaging techniques are used to monitor the heart and lung function in infants and children, providing real-time data on conditions like congenital heart defects or respiratory disorders. This helps in making informed decisions about treatments and interventions[8].

Surgical Planning and Outcomes: Corrective Surgeries for Congenital Defects: 4D imaging helps in planning surgeries for congenital defects, such as cleft palate or spinal deformities, by providing a detailed view of how the tissues and organs move and interact. This results in more precise and effective surgical outcomes.

4D IN DENTISTRY

1. Orthodontics: 4D imaging is increasingly used in orthodontics to track tooth movement over time[9]. Technologies like 4D cone-beam computed tomography (CBCT) allow orthodontists to visualize how teeth move in response to braces or other orthodontic appliances. This real-time tracking improves treatment planning and outcomes, enabling adjustments to be made more effectively during the course of treatment[10].
2. Implantology: For dental implant procedures, 4D imaging helps in planning the placement of implants by providing dynamic visualization of the jawbone and surrounding tissues. This ensures that implants are positioned with maximum precision, reducing the risk of complications such as implant failure or damage to adjacent structures[11].
3. Endodontics: In root canal therapy, 4D imaging assists in the accurate diagnosis and treatment of complex root canal systems. By capturing the intricate anatomy of tooth roots in motion, endodontists can better navigate root canals and ensure thorough cleaning and filling, which improves the success rates of treatments.
4. Temporomandibular Joint (TMJ) Disorders: 4D imaging is particularly useful in diagnosing and treating TMJ disorders. By visualizing the joint as it moves, dentists and oral surgeons can better understand the dynamics of the jaw and identify issues such as dislocations, arthritis, or abnormal jaw movements. This leads to more effective, personalized treatment plans.
5. Prosthetics: In dentistry, this advancement has transformative potential for the creation of facial, ocular, and hand prosthetics. For facial prosthetics, 4D printing allows for the development of adaptive devices that can better mimic natural tissue behaviour, adjusting to facial movements to improve comfort, fit, and aesthetic outcomes for patients with deformities or trauma. In ocular prosthetics, 4D printing facilitates the production of prosthetic eyes that can adjust to changes in the socket's size or shape over time, ensuring a more precise and enduring fit, which enhances cosmetic results and comfort. Additionally, in hand prosthetics, 4D printing enables the creation of prosthetic fingers or hands that can adapt to different tasks or environments, with the ability to modify their stiffness or flexibility based on the user's needs. This results in prosthetics that are not only more functional but also provide a significantly improved user experience.[9]

BENEFITS AND CHALLENGES

The integration of 4D imaging in medical and dental fields offers several benefits, including improved diagnostic accuracy, enhanced treatment planning, and real-time monitoring of procedures. However, it also presents challenges such as the need for advanced equipment, higher costs, and the requirement for specialized training to interpret 4D data effectively. 4D imaging represents a significant advancement in the medical and dental fields, providing a more comprehensive view of the human body in both static and dynamic states. Its applications continue to grow, promising further improvements in patient care and treatment outcomes[12].

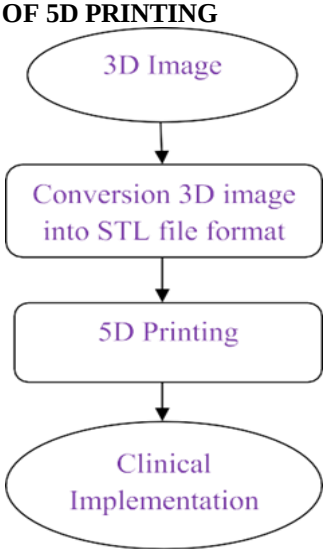
5D PRINTING

The concept of 5D printing originated from American Universityby Mitsubishi Electric Research Laboratories (MERL) by William Yerazunis (2016).[1] It is a latest technological advancement used to manufacture difficult and complex shaped products, implants and devices with much better physical properties than those obtained by three-dimensional (3D) printing[13].

5D PRINTING HAS FIVE AXES

X-axis
Y-axis
Z-axis
Movable print head
Movable print bed

PROCESS OF 5D PRINTING



APPLICATIONS OF 5D PRINTING IN MEDICAL FIELDS

1. Complex Anatomical Models:

Precision: 5D printing can produce highly detailed anatomical models that accurately mimic the complex structures of the human body, which is critical for pre-surgical planning, medical training, and patient-specific treatments.

Multi-Material Integration: The ability to incorporate different materials and mechanical properties within a single print allows for the creation of models that closely replicate the feel and behaviour of actual tissues, bones, and organs.

2. Advanced Surgical Instruments:Precision Manufacturing: The technology enables the production of complex surgical instruments with intricate designs that would be difficult or impossible to achieve with traditional manufacturing methods.

Functional Adaptability: Instruments can be designed with features that change shape or function during surgery, adapting to the specific needs of the procedure.

3. Tissue Engineering and Regenerative Medicine:

Bioprinting: 5D printing is pushing the boundaries of bioprinting by allowing for the creation of more complex tissue structures that can grow and respond to their environment, opening up new possibilities in regenerative medicine.

Dynamic Scaffolds: These can be designed to change shape or properties over time, better mimicking the dynamic nature of living tissues and improving the integration of engineered tissues with the body.

4. Personalized Implants and Prosthetics:

Customization: 5D printing allows for the creation of implants and prosthetics that are precisely tailored to the patient's anatomy. This personalization improves the fit, comfort, and functionality of the devices[14].

Enhanced Strength and Flexibility: With 5D printing, the orientation and arrangement of the printed material can be optimized to enhance the mechanical properties of the final product, making implants and prosthetics more durable and adaptive to the patient's movements.[1]

APPLICATIONS OF 5D PRINTING IN DENTAL FIELDS

1. Endodontics

Enhanced Diagnosis and Treatment Planning: 5D imaging could improve the visualization of root canal systems, identifying additional canals, and complex anatomical structures. It may also aid in dynamic assessment, such as evaluating blood flow or tissue changes over time, allowing for better diagnosis and treatment planning.

Precision in Treatment: Advanced imaging might allow for more precise navigation within the canal system, reducing the risk of procedural errors like perforation or missed canals.

2. Restorative Dentistry

Accurate Marginal Fit: 5D technology could enhance the design and fabrication of restorations, leading to better fitting crowns, bridges, and inlays/onlays. The dynamic aspect may also help assess the long-term performance of restorations under various conditions, such as stress or wear.

Material Selection: It could provide insights into how different materials perform over time under the oral environment, aiding in the selection of the most suitable materials for restorations.

3. Prosthodontics

Improved Prosthesis Design: With 5D imaging, the design of dentures, implants, and other prostheses can be more tailored to the patient's anatomy and functional needs, taking into account dynamic factors like muscle movement and occlusal forces.Predictive Modeling: The ability to model changes over time could allow prosthodontists to predict how a prosthesis will perform and adapt to changes in the oral environment, leading to longer-lasting solutions[15].

4. Pedodontics (Pediatric Dentistry)

Early Detection: 5D technology could help in the early detection of developmental issues, caries progression, or trauma effects, allowing for timely and more effective interventions in children.

Behavioural Insights: The integration of dynamic data might offer new ways to assess and respond to children's dental health needs, potentially improving cooperation during procedures through better understanding of their responses.

5. Oral and Maxillofacial Surgery

Surgical Precision: 5D imaging could significantly enhance the planning and execution of complex surgeries by providing real-time, dynamic visualizations of anatomical structures. This could be crucial for procedures like orthognathic surgery, tumor removal, and implant placement. Postoperative Monitoring: Post-surgery, 5D technology could monitor healing and detect complications early,

improving patient outcomes and reducing recovery times[16].

6. Orthodontics

Comprehensive Treatment Planning: In orthodontics, 5D imaging could provide a deeper understanding of the interaction between teeth, jaws, and soft tissues over time. This could lead to more personalized and effective treatment plans. Monitoring Treatment Progress: It could be used to dynamically monitor the progress of orthodontic treatment, allowing for adjustments in real-time based on how the teeth are moving and the overall changes in the oral environment.[17]

CONCLUSION

In conclusion, the ongoing advancements in printing technologies, particularly 5D printing, are revolutionizing the medical devices industry by enabling the creation of highly complex, durable, and precise objects that were previously unattainable with traditional methods. While 3D printing has already transformed healthcare with its ability to rapidly produce customized medical models and prosthetics, 4D and 5D printing take this innovation even further. The incorporation of smart materials in 4D printing and the enhanced dimensional control of 5D printing are enabling breakthroughs in material science, drug delivery systems, and personalized medical treatments. These advancements are poised to significantly improve patient care and broaden the scope of possibilities in medical research, prosthetics, and bioengineering.

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REFERENCES

1. Haleem A, Javaid M, Vaishya R. 5D printing and its expected applications in Orthopaedics. Journal of clinical orthopaedics and trauma. 2019 Jul;10(4):809.
2. Salmi M. Additive manufacturing processes in medical applications. Materials. 2021 Jan 3;14(1):191.
3. Brown AC, De Beer D. Development of a stereolithography (STL) slicing and G-code generation algorithm for an entry level 3-D printer. In2013 Africon 2013 Sep 9 (pp. 1-5).
4. Jeong M, Radomski K, Lopez D, Liu JT, Lee JD, Lee SJ. Materials and Applications of 3D Printing Technology in Dentistry: An Overview. Dentistry Journal. 2023 Dec 19;12(1):1.
5. Aimar A, Palermo A, Innocenti B. The role of 3D printing in medical applications: a state of the art. Journal of healthcare engineering. 2019;2019(1):5340616.
6. Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, Lu X, Shi H, Lee ES, Jiang HB. A review of 3D printing in dentistry: Technologies, affecting factors, and applications. Scanning. 2021;2021(1):9950131.
7. Mohd Javaid, Abid Haleem. "4D printing applications in medical field: A brief review", Clinical Epidemiology and Global Health, 2019.
8. Cai J, Chang Z, Wang Z, Paul Segars W, Yin FF. Four-dimensional magnetic resonance imaging (4D-MRI) using image-based respiratory surrogate: a feasibility study. Medical physics. 2011 Dec;38(12):6384-94.
9. Javaid M, Haleem A, Singh RP, Rab S, Suman R, Kumar L. Significance of 4D printing for dentistry: Materials, process, and potentials. Journal of Oral Biology and Craniofacial Research. 2022 May 1;12(3):388-95.
10. C. Y. Ho ."Comparison of Three-dimensional Arch Changes Between CAD-CAM and Traditional Brackets." BMC Oral Health 2019;19(1):286.
11. R. S. Subburaj, A. V. Prakash, S. T. Shaikh, M. G. Jagadeesh, and D. R. Kumar. "Smart Dental Implants: A Review," Journal of Indian Prosthodontic Society 2016;16(4):315-322.
12. Bhanu Prasad K , Dr. Lakshmana Rao B, Dr. T.S.V. Satyanarayana, A Sathvika,, Devi SuvarchalaA,Yasaswini K. '4 D Printing' in Dentistry, A Paradigm Shift! - A Narrative Review. Int J Sci Res Eng Manage 2024;8(5):1-7.
13. K.JayaLakshmi et al. '5d Printing' -The New Era In Dentistry! -A Narrative Review. International Journal of Scientific Research in Engineering and Management. May2024. Volume 8 Issue 5.
14. Abid Haleem and Mohd Javaid. 5D printing and its expected applications in Orthopaedics.J ClinOrthop Trauma. 2019 Jul-Aug; 10(4): 809–810.
15. Haleem A, Javaid M. Future applications of five-dimensional printing in dentistry. Current Medicine Research and Practice. 2019 Mar 1;9(2):85-6.
16. Anas S, Khan MY, Rafey M, Faheem K. Concept of 5D printing technology and its applicability in the healthcare industry. Materials today 2021; 56(3): 1726-732.
17. Sadiq sha H A J, Pradeep Patil.Review on 4D and 5D Printing Technology. International Research Journal of Engineering and Technology.2020 June Volume 7, Issue 6.