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REVIEW ARTICLE

5D Printing: Applications in Medical Field

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ABSTRACT
Complex surgery, presurgical planning, replacement of faulty bone, teaching, research, retraining, and other healthcare applications have all benefited from three-dimensional (3D) printing. There seem to be, therefore, considerations for placing stronger curved implants in the body of the patient. As a result, five-dimensional (5D) printing is being used in the health industry to enhance implant efficiency and durability for long-term treatment. William Yerazunis proposed the notion of 5D printing to improve the strength of 3D printed objects. A new branch of additive manufacturing is 5D printing. The print head and the printable item have five degrees of freedom in this technology. It creates curved layers rather than straight layers. In this operation, the print portion moves while the printer head prints. Using five axes make printing curved layers a breeze. Computer-aided design (CAD) data is used to acquire the model parameters. There seems to be materials conservation in this procedure. 5D printing gives complicated designs a better dynamic strength and flexibility throughout its printing procedure. Manufacturing, healthcare and also other areas will benefit from this innovative digital printing technology.
Keywords: *3D printing, 4d printing, 5D printing, healthcare, medical, applications*

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INTRODUCTION
3D printing is another name for additive manufacturing (AM). Because 3D printing uses a traditional fabrication approach, it is impossible to create complicated structures3D printing is a technique for turning a three-dimensional model into a tangible object, typically, numerous thin layers of material are laid downward [1]. A CAD model is created from a digital object. The CAD model has been divided into layers. The stereolithographic method, which has x, y, and z axes, lies at the heart of 3D printing. Fast accuracy, high speed, a wide range of material qualities, and low cost are all benefits of 3D printing [3]. In the production sector, 3D printing is now being utilized to create components. It is possible to create both simple and complex components. 3D printing is widely utilized in the automotive industry. It's used to make metal, rubber, and plastic things. It is also utilized in the construction of homes, where the concrete mixture is utilized throughout the material [15]. The flow diagram of 3D Printing Technology, which is widely used in current businesses, is shown in the figure 1.

4D PRINTING
4D printing is a type of additive manufacturing that allows objects to remodel or self-assemble over time. 4D printed materials react to surrounding influences like humidity, temperature, and other factors, changing their structure as a result. Smart materials and advanced designs are used in 4D printing, which are "programmed" to cause your 3D print to alter shape. 4D printing is a research area that arose from 3D printing [16]. It contains four dimensions that are involved in a sophisticated substance which has the ability to respond to external stimuli, and 4D printing allows the production of dynamically programmable shapes on demand by incorporating the temporal dimensions. The x, y, and z axes are the

four dimensions of 4D printing, and the fourth dimension is time, which saves up to 90% of time and material. The flow diagram of 4D Printing Technology, which is widely used in modern industries, is shown in figure 2 [1].

5D PRINTING AND WORKING OF 5D PRINTER

Mitsubishi Electric Research Lab was the first to implement 5D printing as a concept (MERL). According to William Yerazunis, the object is produced using five separate axes in 5D printing (Senior Principal Research Scientist). It enables the creation of a complex structure having high durability [17]. The printing head and printable item rotate in five degrees of freedom along the x, y, and z axes in 5D printing, a breakthrough advanced production technology. The five axes used to create items give rise to the moniker 5D Printing. The printing head can move in three directions (axes) in this printing, and the printing bed is capable to move in two directions (axis). Printing curved layers is a breeze when you use five axes. The model characteristics are determined using computer-aided design (CAD) data. This process appears to be material conservation. As during printing process, 5D printing provides difficult designs more dynamic strength and flexibility. This cutting-edge digital printing technique will aid production, medicine, and a variety of other industries. While printing, both the printing head and the printing bed can move at the same time. The product is created by layering horizontally. As a consequence, concave and convex pieces could indeed be created with great accuracy and within design limits [18]. It accurately creates curved layer or concave shapes according to design limitations. As the printing head prints in five axes at the same period, the imprinted part rotates. The printing bed, along with the x, y, and z axes, moves both forward and backward concurrently, allowing the item to be printed from all five axes rather than just one.5D printing is mostly employed in the healthcare and automobile industries. Ramping up production of healthcare equipment with high tensile strength. This holds great potential to manufacture any curved surface that is used in automotive applications [1]. 5D printing is a huge technical development for elements which need to be durable in needed to execute in the business, as well as meeting industrial requirements and relevant legislation. Even while it requires a significant number of fillers and support, as well as a difficult design, a concave cap, for example, could not be 3D printed. Because it can print curved layers, 5D printing makes printing easier. The example of a 5D printed concave cap is illustrated in figure 3 and it is clear that it is unable to be created via 3D printing [2].

HALO 5D PRINTER

Ethereal Machines, Bengaluru, India, has made a breakthrough in additive printing with its innovative and forward-thinking "Halo 5D printer." At the CES 2018 at Las Vegas Convention Centre, it was won the 'Best of Innovation' prize in the 3D printing genre. The device is able to rotate and rotate the pieces to create intricate designs for aesthetic or functional objectives. To print items in 5 axes, this necessitates a suspension system similar to that seen in 3D printers (3axis of movement and 2 rotational axes). Ethereal team utilised subtractive and additive approaches to come up with a version on 5-axis machining using established 3D printing techniques and CNC routers [2]. The image of Ethereal Halo 5D Printer is shown in figure 4.

APPLICATIONS OF 5D PRINTING:

Major medical applications of 5D printing are listed in table no.1

APPLICATION OF 5D PRINTING IN DENTISTRY:

Five-dimensional (5D) printing is a new branch of additive manufacturing (AM) that has a great deal of potential in medical, dental, and other related sectors. It is a recent technical innovation that allows manufacturers to create challenging and complicated shaped items, inserts, and devices with far superior physical qualities than three-dimensional (3D) printing. 5D printing is being used to create some surgical equipment, such as dentures, dental implants, and other complicated-shaped things. A tooth with curved shapes and curved parts is also made precisely, with the necessary surface polish and durability. The equipment's strength is higher, and this technique is the ultimate method to get it done. In dental, complicated and sturdy implants with curved surfaces are necessary. This complex and curving structure is produced efficiently and with maximum strength using five-dimensional printing. This innovative technique becomes a breakthrough production technique for generating high-strength dental implants, orthodontic braces, crowns, aligners, bridges, and instruments using computer-aided design (CAD) data. A patient's missing tooth can be simply produced with the needed dependability and surface polish. Consequently, it produces dental surgical guides that are extremely precise. It is beneficial to create orthodontic models and aligners in accordance with desired strength. Manufacturing complex shapes, planning, education, and guaranteeing dependable operation will all benefit from these technologies. These CAD files are created using a dental 3D scanner and a variety of designer applications. This approach possesses the capacity to tackle a difficult problem while also opening up new opportunities in dentistry. The technique used by 5D printing to create dental implants and instruments is represented in figure 5 [4]. The procedures in the five-dimensional printing process are nearly identical to those in 3D printing. A 3D picture is made using proper dental 3D scanner/designing software that is subsequently converted to standard triangulate language (STL) format or a printable format. These files could be easily created via 5D printing, then tested and used in clinical dental settings [4]. The key benefit is that, this technique is that it enables for the production of stronger curved-shape products/implants, as well as the process of generation of parts with curved layers rather than flat layers. The uncertainties of products formed by a flat layer is avoided with this printed object with a curved layer. It is currently undergoing investigated whether 5D printed objects are more durable than 3D printed ones. As a conclusion, we anticipate that any complex curved-shape dental product with much increased power and dependability for surgery will increase comfort of lives for patients [4]. In the long run, this technology will make the job of a surgeon much simpler, with far greater reliability and less health consequences. It may be accustomed to print dental implants made of various biomaterials. Five-dimensional printing technique will enhance any curved shape product, such as stents, bones, dentures, and other dentistry instruments and devices [19]. This technique facilitates the growth of digital dentistry by allowing for mass customization depends just on person's digitized information. When it comes to lowering the price of implantation, 5D printing is preferred over 3D printing since it consumes fewer materials. This technology has the potential to be effective in dentistry in the coming years, and it will be beneficial in challenging instances [20]. It has the potential to tackle a variety of dental difficulties, including improving existing dental practises and meeting bespoke complex shape requirements. It is necessary to do application-based research, advancement, and modification in the field of dentistry [6].

APPLICATION OF 5D PRINTING IN ORTHOPEDICS

Artificial bones with exceptional strength may be made using 5D printing technology. Because curved pieces demand high precision and a high level of surface polish. The manufacture of human body components necessitates extreme precision and a high level of strength. Because these components are required for use within your body. As a result, correct shape and size are required. A 5D printed model could be used to create surgical artificial bone. Synthetic bones manufactured with 5D printing are necessary to offer improved toughness to such bone replacement because human bones are not flat and have a groove. This technology has a lot of potential in terms of meeting this basic requirement [7]. The use of complicated and robust implants with curved surfaces is vital in orthopaedic surgery. 5D printing can create these sophisticated surgical implants according to the patient's actual operation and may also be used for surgical planning, training, and learning. As a result, 5D printing can quickly create a complicated, bent superstructure which requires a lot of toughness [5]. 5D printing employs a variety of programmable materials that can alter shape and function in response to time and temperature. Because of their thermo-mechanical qualities, these materials are referred to as smart materials. Such sophisticated materials can be used to create prostheses for difficult orthopedic surgical interventions using data from computer tomography (CT) and magnetic resonance imaging (MRI) scanning procedures. 3D slicer, Mimics, OsiriX Imaging Software, Magics, 3D doctor, and In Vesalius are just a few of the apps that can easily turn this dataset to 3D CAD file format used in 5D printing [8].

APPLICATION OF 5D PRINTING IN PROSTHETICS

Prosthetics are artificial devices that replace body parts that have been lost or impaired from childbirth due to accidents. 5D printing is utilized to construct complicated artificial human parts with great durability implantation, such as the hand, leg, lower jaw, and dentures.. Concerns with prosthetics include their look, heaviness, grabbing strength, and absence of tactile senses, all of which contribute to increased rejecting rates. Patient rejections can also have catastrophic implications, resulting in joint and muscle atrophy, excruciating inflammatory, among other possibly fatal problems. However, with 5D printing, it is now possible to reduce the number of assembly steps required to manufacture prosthetics while also developing more sophisticated designs, as demonstrated by a series of recent projects. This mechanism aids in the straightening of bones.[1] The cast is digitized with a basic, low-cost scanner, and the resultant data is forwarded to a remote professional prosthetist for confirmation and evaluation. The data is then sent to the 5D printer closest to the patient's location, where the prosthesis is produced and dispatched. Such prosthetics may also be created considerably more quickly; an arm can be created in a single day. Customers may also readily customise their purchases, which is another appealing feature for children. Colours and designs can be chosen by the individuals to suit personal preferences. 5D printing technology is commonly used to create prosthetic body parts. These portions, as we all know, require more strength. These man-made bodily components are frequently used in their intended applications. Such technique can produce high-strength patient-specific prosthetics since conventional prostheses should bear the pressure of the human body. This 5d printer technology provides such high strength.

APPLICATION OF 5D PRINTING IN PERSONALISED NANOMEDICINES

Personalized medicine is a new medical field that utilises a patient's genomic makeup to help direct choices about illness management, diagnostics, and medication. Personalized medicine is the practise of designing a medication to be as unique as the patient. The method is based on finding genetics, epigenetics, and medical data that helps us to gain a better understanding of how a person's unique genomic portfolio makes them sensitive to medical disorders. For customised medicine, 5D printing combines data used to produce 3D models with data on physiological activity. 3D printing allows for three-dimensional morphological characteristics reproduction, 4D printing allows for object functionalization through the use of bio-inks that are better suited to the finished applicability, and 5D printing incorporates data used to create 3d as well as data on physiological functions for personalised therapy. We can show how the 5D additive manufacturing process is used to generate customised representations of patients' pathologies. We can employ existing 3D printing technology to discover the operative processes and related factors capable of achieving the best fit between the digital model and the finished object in detail. Thus, we can choose bio-inks and innovative composite materials to meet the functional requirements of the final product (4D). Finally, merge the constructed devices with the shape derived from the patient, customising macro/micro morphologies and biological features (5D). Following that, pharmacological integration and in vivo analysis allow tailored therapy to be implemented. We are able to transition from the functionalisation approach (4D) to the customization approach because to the favourable outcomes gained from in-vitro and in-vivo research (5D). As a result, we functionalized the patient target structure in order to provide a high-definition digital image for the 5D models. [9]. 5D printing combines data from 3D models with information about physiological activity to provide individualised therapy [10]. We can use electromagnetic (EM)technologies like computer tomography or magnetic resonance imaging to acquire the patient's target structures, but the resulting anatomical component is not always conveniently printable. The high number of variables generated by EM technologies, as well as the limitations of elaboration software, may not always allow for independent reconstruction of the specified item. In reality, the development of bionic devices necessitates the creation of a predictive algorithm based on operational processes for implementation via a new form of biofactory (industry 5.0) [11].

APPLICATION OF 5D PRINTING IN SURGICAL EQUIPMENTS AND MEDICAL TOOLS

Manufacturing surgical equipment is a delicate business. We need excellent cutting precision, sharp cutting edges, good strength to withstand the force exerted, and suitable forms. These kinds of requirements are met by this technology. 5D printers can make sterile medical equipment like forceps, haemostats, scalpel handles, and clamps. These devices can be used to operate on small areas without giving the patient any additional harm. The ergonomics and aesthetics of the equipment assist the surgeon in properly gripping it. It enhances precision while lowering the risk of an accident. This technology is used to make Monopolar diathermy, DeBakey forceps, mosquito forceps, and the Deaver retractor. High-strength customised medical tools and equipment are created via 5D printing. It can create any tools that match the patient with the help of CAD data. In craniofacial and head and neck surgeries, this approach allows surgeons to better understand complex structures, fractures, and abnormalities. Furthermore, when combined with digital pre - surgical planning, this technique has the greatest benefit. As an outcome, surgical CAD/CAM (computer-aided manufacturing) guidance and patient-specific implants (PSI) can be developed to improve surgical precision and cut down on surgery time, including for increasingly intricate reconstructions. Patient-matched anatomical models, prosthetics, and surgical guides, which are aids that assist surgeons decide just where cut when in a surgery, are all examples of medical equipment that are printed just at point of care [21]. Surgery is used to create humanised design tools that are stronger, more appealing, and more exact. Produce surgical attachments, kits, and patient care devices as needed. Easily creates surgical tools with a variety of design, analytical, and production software packages, resulting in greater strength. Orbital floor fracture reconstructions are the most prevalent surgical application of this technology in craniomaxillofacial injuries. The purpose of this type of surgery is to keep the orbit's form and volume while also restoring its function, correcting any aesthetic issues, and preventing future complications. Surgical section pipes, for example, are simple to construct and have a longer lifespan. Provides satisfaction to the patient. [1]

APPLICATION OF 5D PRINTING IN ADDITIVE MANUFACTURING

The essence of 5D printing is a mix of additive and subtractive processes. According to Mitsubishi Electric Research Laboratories (MERl), determining how 5D printed parts will be used needs extensive analysis of the object being manufactured beforehand. Complex constructions and designs that demand a lot of strength are the greatest candidates for 5D printing [12]. Additive manufacturing (AM), often known as 3D printing, was first developed as a rapid prototype approach in the 1980s and is today regarded as a production process that functions similarly to traditional manufacturing processes. AM has had an impact on industries as diverse as aircraft, automobiles, construction, medicine, and the military. It enables for greater products designing freedom, as well as a significant reduction in material consumption and product customisation costs [13]. AM methods are categorised by ASTM International into seven classifications: material extrusion (e.g., fused deposition modelling—FDM), powder bed fusion, vat photopolymerization (stereolithography—SLA), material jetting (e.g., PolyJet), sheet lamination, directed energy deposition, and binder jetting. Additive manufacturing includes rapid prototyping (RP), Direct Digital Manufacturing (DDM), and Layered Production [14].

ADVANTAGES OF 5D PRINTING OVER 3D AND 4D PRINTING

Comparison of various parameters of 3D, 4D, and 5D printing is shown in table no. 2.

Table 1: Applications of 5D printing

Sr no.	APPLICATIONS	DESCRIPTION
1	**Medical instruments**	5D printing is beneficial to create high-strength bespoke medical tools and equipment. With the aid of CAD data, it may construct any tools that matches the patient.
2	**Surgical instruments**	Uses surgeries to create humanised design tools that are stronger, more appealing, and much better exact. As needed, manufacture surgical attachments, kits, and patient care devices. Easily develops surgical tools using a wide range of design software packages, in addition to analysis and production software applications, resulting in increased strength.
3	**Bone traction**	This combination of mechanisms aids in the straightening of the shattered bones. Bone tractions are created by this technique based on the amount of weight placed on it.
4	**Body Implants**	Humans physical components are curved and lacking sharp points, rather than being geometrical in structure. As a result, curved pieces are essential to manufacture correct fit implants. These implants are used to replace biological structures that have been lost. Implants of any form may be made with 5D printing, and they are extremely strong.
5	**Prosthetic body parts**	Prosthetics are replacement implants which are used to replace body parts that have been lost due to disease, trauma, accident, or congenital flaws. Since generic prosthetics should bear the load of a human body, this technique allows for the creation of increased strength, individual specific prosthetics.
6	**Bone traction**	This combination of mechanisms aids in the straightening of the shattered bones. Bone tractions are created by this technique on the basis of the quantity of weight placed on it.
7	**Medical pipes**	Medical pipes, such as surgical section pipes, are simple to make and last better. Gives the patient a sense of accomplishment.
8	**Heart valves**	The main aim valves in the heart is to maintain the flow of blood in the appropriate path all through the heart. This method produces heart valves that are reasonably reliable.
9	**Medical fasteners**	Medicinal fasteners do have capacity to converse with surgical implants and the human body. The technical specifications are met with 5D printed medical fasteners.
10	**Dentistry**	Production of dental grills and dental implants.

FUTURE APPROACH OF 5D PRINTING

5D printing has the potential to democratise the manufacturing of commodities food & beverages to medical aid and in medical field to massive corals. 5D printing devices may one day be found in houses, organizations, crisis zones, and even outer space. 5D printing is frequently utilized in clinical therapy for a variety of surgical applications, including vascular surgery, neurosurgery, clinical diagnostics, and patient-specific implant and prosthesis creation. Emerging dynamics may necessitate more use of 5D printing in hospitals and other health-care facilities. The expanding elderly population has fuelled demand for organ donors, according to a recent Global Data research on 5D printing in healthcare, while gene therapy employing bio printed, patient-derived stem cells allow for individualised treatment of various ailments. 5D bioprinting, or the printing of organs, is still a long way off, but progress is being made quickly. The integration of virtual and augmented reality with 5D printing has a huge amount of potential for complex operations that have a variety of visual sophistication and a lot of anatomical variances. We can achieve such high degree of efficiency in production by utilising this printing techniques. It allows for the creation of complex, greater strength pieces. The printing industry will be able to grow even farther in the future. Modern technology will aid in the production of components that are quicker, better, accurate, and efficient. 5D printing has the potential to produce disruptive innovation in Orthopaedics in the future. It will open up endless possibilities and provide outstanding service in order to preserve the patients' lives. This method appears to be capable of producing complex shaped implants to meet acute medical and orthopaedic needs.

Table 2: Advantages of 5D printing over 3D and 4D printing

DESCRIPTION	3D	4D	5D
DEFINITION	The process of creating a 3D object from a CAD model by layering print material.	External factors such as light and heat can cause 3D printed objects to change shape.	The object is built with a 5 axis 3D printer.
RAW MATERIAL	Nylon, Carbon, PLA, ABS, Polycarbonate	Shape Memory Polymer (SMP), Hydrogel, Shape Memory Alloy (SMA)	PLA, ABS, Polycarbonate, Nylon, Carbon, Metal, On-metal
PRINTING HEAD	Movable	Movable	Movable
PRINTING BASE	Stationary	Stationary	Movable
DEGREE OF FREEDOM	3	3	5
PRINTED OBJECT	Static	Dynamic	Static
DESIGN CONCEPT	A 3D digital object	3D digital object with deformations	3D digital object with five degrees of freedom

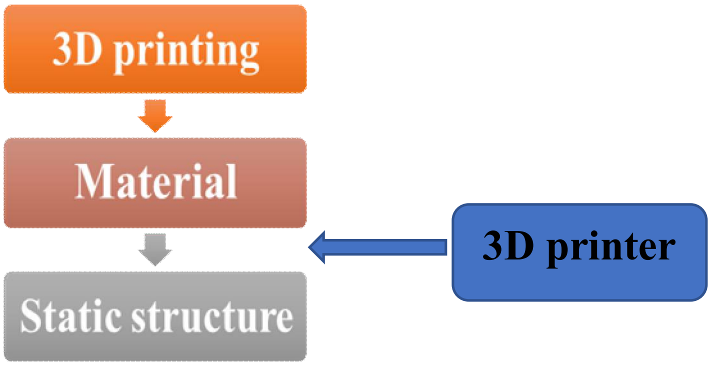

Figure 1: Flow diagram of 3D printing.

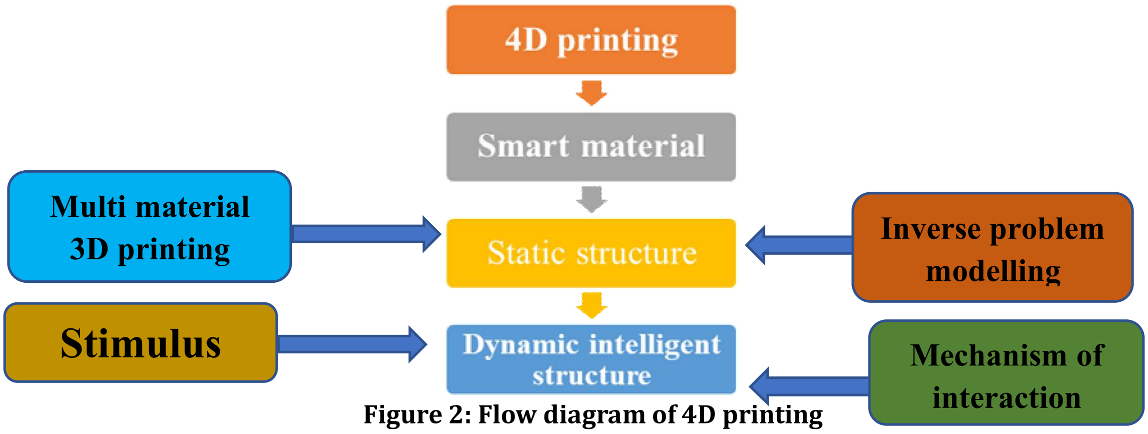

Figure 2: Flow diagram of 4D printing

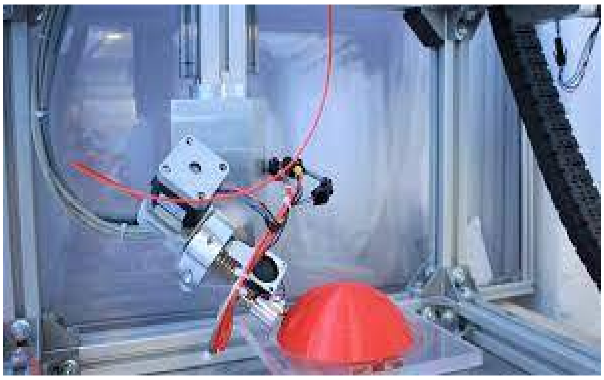

Figure 3: 5 axis 3D printer [2]

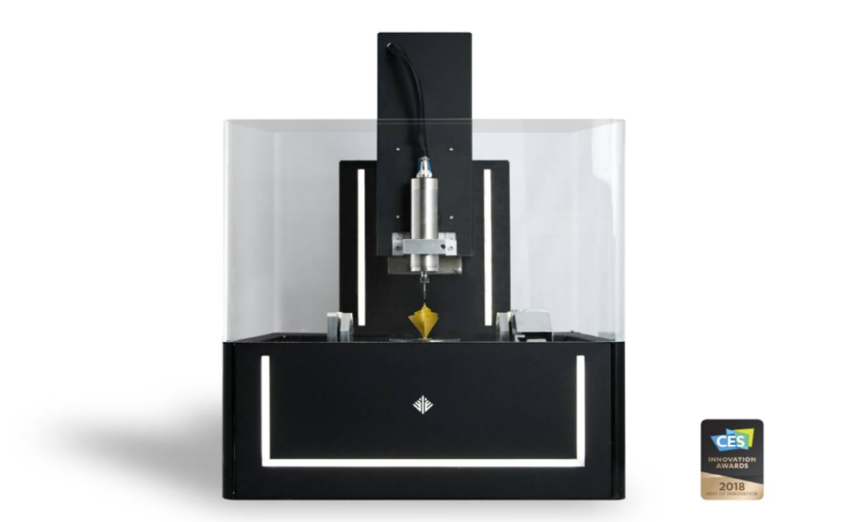

Figure 4: Ethereal Halo 5D Printer [2]

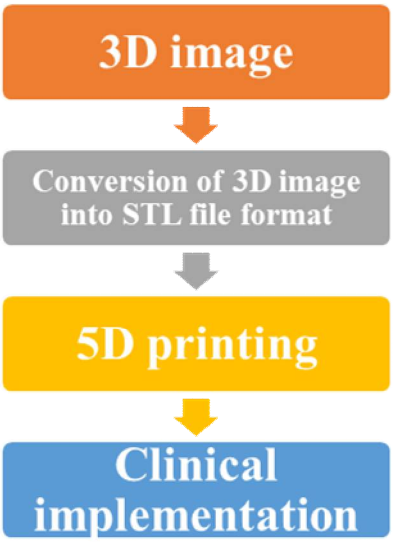

Figure 5: Process chart of 5D printing dentistry

CONCLUSION

The constraints of 3D and 4D printing are eliminated with 5D printing. It is extremely strong and may be used to make bent and complex sculptures. Researchers are attempting to increase the capability of this technique to withstand pressures of up to 3.4 MPa. As a result, it has a wide range of uses in medicine and industrial. Five-dimensional manufacturing reduces roughly 25% of the material used in traditional 3D printing. It cuts down on waste by 20 to 30%. This technology will be widely used in all healthcare market segments in the future because of their multiple advantages. Smart materials and morphing structures are becoming increasingly common as 5D printing progresses. The focus is on improved materials, tougher materials, and considerably lower resource consumption, which means fewer processes.

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