Current status and applications of 3D scanning in dentistry

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ABSTRACT

3D scanning technologies are used to convert a physical model into digital 3D computer-aided design (CAD) file. This digital output is well used for designing and fabricating customised parts through additive manufacturing (AM) technologies. There is a need to identify the contemporary level of adoption of 3D scanning technology in the dental area. This structured literature review based research first tries to identify different types of scanning technologies and then the necessary steps as used to create a design and manufacture dental implant using the 3 D scanning. A large number of the relevant research papers on 3D scanning applications in dentistry are identified through Scopus and analysed using bibliometrics. This analysis indicates towards an increasing trend of research on 3D scanning applications in the field of dentistry. Different applications of this technology are discussed in the context of dentistry and observed that this technology create innovation in dental products for a dentistry lab. The dentist can take advantages of this technology towards designing custom teeth, crown, braces, dentures, veneers and aligner. 3D digital models also support teaching in dental education for better understanding and practice of the teeth anatomy. Along with the scanning of the complete denture of the patient, direct printing of the same is done by using AM technology produces denture which directly fits the mouth of the patient. It helps reduction of the complexity and production cycle time. 3D scanning technologies seem to have the potential for denture positioning and denture retention and improvement in existing dental implants.

1. Introduction

Dental laboratories are rapidly moving towards incorporating digital format and processes including 3D scanner, CAD and different additive manufacturing technologies. The 3D scanner captures data of unique dental anatomy of patient and converts into 3D digital CAD file. This file is easily editable/printable by functional additive manufacturing technologies. It improves the level of communication between the dentist and the patient. A 3D scanned model by this technology can help the technician to advise the patient. In dentistry 3D scanner capture data by projecting light source onto the object such as teeth, dental arches and implant scan bodies.[1,2]

Dentist required clear and concise picture during surgery for customised treatment. 3D scanners are quicker and more comfortable which captures multiple images and further merged to form a complete digital 3D model. Apparatus of these technologies have structured illumination and represents an object in a digital 3D format. It consists of a light source and camera/s. Light is projected on the surface of the object and camera capture the data. The accuracy of the scanned object depending on the camera resolution.[3,4]

3D Scanners are automatic 3D acquisition devices which creates the digital 3D model from real 3D objects effectively in lesser time cost-effectively. It has high accuracy, affordable cost of product scanning, easy to use to produce a colour data. In the current scenario, 3D scanning technology is growing in many fields including those in education, medical, design which helps to create a design for the manufacturing of prototype. In design, manufacturing and inspection of parts, it plays a primary role for complex surfaces. For reverse engineering and inspection, a 3D scanner is a useful tool as it requires lesser time for capturing digitised surface data.[5,6]

There are many disadvantages of traditional method for measurement, such as confinement of the object of measuring to size; a regular shape and is more troublesome, laborious and time-consuming. However, three-dimensional scanning technologies can scan complex objects with excessive benefits like safety, high speed, and precision, especially time and cost saving. In the medical area, 3D scanning application is also widely used in visualisation and reconstruction of the human body parts such as orthotics, prosthetics and bones.[7–10]

2. Need for the study

In dentistry, customisation is necessary because the data of all

human being are not same. We need to be identifying the different scanning technologies and creation of a 3D physical dental model by adopting 3D scanning. The study shows the status of research carried out by 3D scanning and contribution of its application in dentistry. There is a need to undertake study for determining how 3D scanning helps to fulfil various requirements by using additive manufacturing technologies in lesser time with lower costs.

3. Research questions

This article addresses the following research questions:

RQ1: To study different types of scanning technologies with a brief description along with primary references.
RQ2: To identify relevant research articles on the 3D scanning applications in dentistry through Scopus and studied using bibliometric analysis.
RQ3: To identify and discuss steps used to create 3D dental implant using 3D scanning technique.
RQ4: To identified major 3D scanning applications in dentistry with a brief description along with primary references.

4. Types of scanning

Various technologies are which are being developed used to obtain data of the object, patient body, instruments or models. Table 1 discusses various technologies as used to scan models.

All these scanning technologies have a different application in industries, medical and in dentistry which help to solve different problems. 3D scanning gives an accurate measurement of mouth, teeth and jaw for better understanding before surgery. Innovation is an essential requirement in every field carried out by research, and this technology is also successfully used for reconstructive surgery like dental implants.[25]

5. Benefits of 3D scanning in dentistry

3D scanning has various benefits in dentistry. It efficiently designs crown, implants and bridges in lesser time and cost. Various benefits of 3D scanning in dentistry are as under:

➢ Rapid production with customised design
➢ Comfort for the patient
➢ Time and cost efficiency
➢ Reduced risk
➢ Effective planning for the procedure and simplified procedure
➢ Better communication
➢ Improved learning
➢ View dental anatomy from different angles
➢ Increased success rate of treatment

6. Research status on 3D scanning in dentistry

Scopus database is used to identify the research articles in the area of 3D Scanning application searching keywords as "3D scanning" "Dentistry"; here we identified 18 articles published in this area till June 2018. The first research article on 3D scanning in dentistry got published in 2006. In each year of 2007, 2008, 2009, 2010, 2011 there was only one article published, in 2013, no article was published in this field. In 2014 and 2015, two articles were published every year. In 2016, one and in 2017 five articles were published, surprisingly in 2018, no article is published up to mid-June in this area.

There is a sustained increase in articles related to 3D scanning in dentistry. Fig. 1 shows the details of the papers published by different journals on 3D scanning in dentistry; this also shows the top five journals in this area. Out of top five, Forensic Science International, Journal of Forensic Sciences and Operative Dentistry have highest publications of two. British Dental Journal and European Journal of Dentistry have one publication each. Other sources and journals also

Table 1
Types of scanning with a brief description.

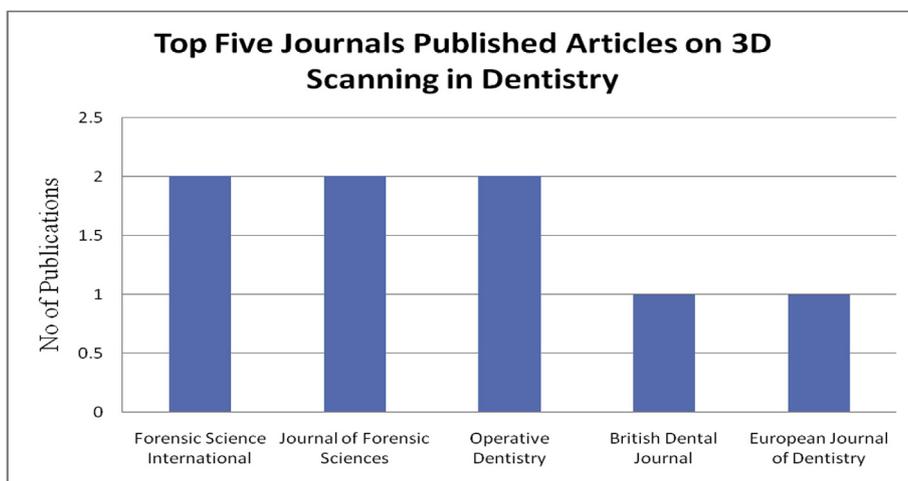| S No	Types of Scanning	Description	References
1	Mechanical scanning	• Measuring arms and coordinate measuring machines (CMM) contact scanner which is also known as mechanical scanners • Obtaining the information through selected points rather than the entire surface	Cremer, 2001[11]; Griffa, 2008[12]
2	X-ray	• Used to produce an image of soft tissue such as organs, skin that cannot absorb high-energy rays, and pass beams through them • Capturing the status of dense materials like bones who absorb the radiation through the X-rays • Like a camera, X-rays are also developed on X-rays films depending upon the exposure area • Used by dentists to diagnose and for a broad variety treatment	Latos and Janóczki, 2011[13]; Bogue, 2010[14]
3	Optical scanning	• This scanning technique works on the photographic principle • The object is scanned with several angles/positions and combine all the scans subsequently that create digitised 3D image	Rokicki et al., 2016[15]; Wojciechowski and Suszynski, 2017[16]
4	CT scan	• CT scan sends X-ray beam to the body that moves through an arc and captures many pictures • CT scan see inside tissue/solid organ having a different level of density • It provides detail information about the human body	Keeling-Roberts 2002[17]; Zeng et al., 2008[18]
5	Laser scanning	• Working of laser scanning is based on the triangulation principle • Light reflected off from the object is sensed which capture data • The angle of impact and position of the object is required appropriately during scanning	Momin et al., 2012[19]; Hanipah et al., 2018[20]
6	Ultrasound	• Ultrasound produces inside pictures of the body by using sound waves • Helps to diagnose, the cause of swelling, pain and infections in the internal organs of the body • Also, help in diagnose of heart conditions, guide biopsies and assess damage after a heart attack • This scanning technology is non-invasive, safe and does not use any ionising radiation	Vaezi et al., 2012[21]; Torres et al., 2015[22]
7	MRI Scan	• It uses powerful magnetic field and radio frequency pulses to achieve the detailed picture of bone, soft tissues, organs and other internal structure of the body • This scanning technology also differentiates normal and abnormal tissue • It helps to obtain an accurate diagnosis	Tischler et al., 2009[23]; Rausch et al., 2003[24]

Fig. 1. 3 D scanning in dentistry: Top five Journals (Source: Scopus).

one publication each these includes Lecture notes in electrical engineering, Quintessence international, International journal for numerical methods in biomedical engineering, International journal of legal medicine, Journal of orofacial orthopaedics, Progress in biomedical optics and imaging proceedings of SPIE, Romanian biotechnological letters and Russian open medical journal.

Fig. 2 shows the area wise research on 3 D Scanning in dentistry; it observes that medical area published 24 per cent 3D scanning papers. Dentistry area contributes 17%, Biochemistry, Genetics and Molecular Biology give 14% contribution, Engineering 10%, computer science 7%, material science 7%, physics and astronomy contributes 7%. Other areas also contribute 14% in this field that includes Agricultural and Biological Sciences, Environmental Science, Immunology and Microbiology and Mathematics.

Observed from the Scopus data, analysed that there is less work done in this area but applications of 3 D scanning in dentistry are increasing.

7. Steps to create 3D dental implant using a 3D scanning technique

3D digital model scanned by a 3D scanning technology provide complete and better information to the dentist and the surgeon. This 3D scanned model is easily printable by additive manufacturing
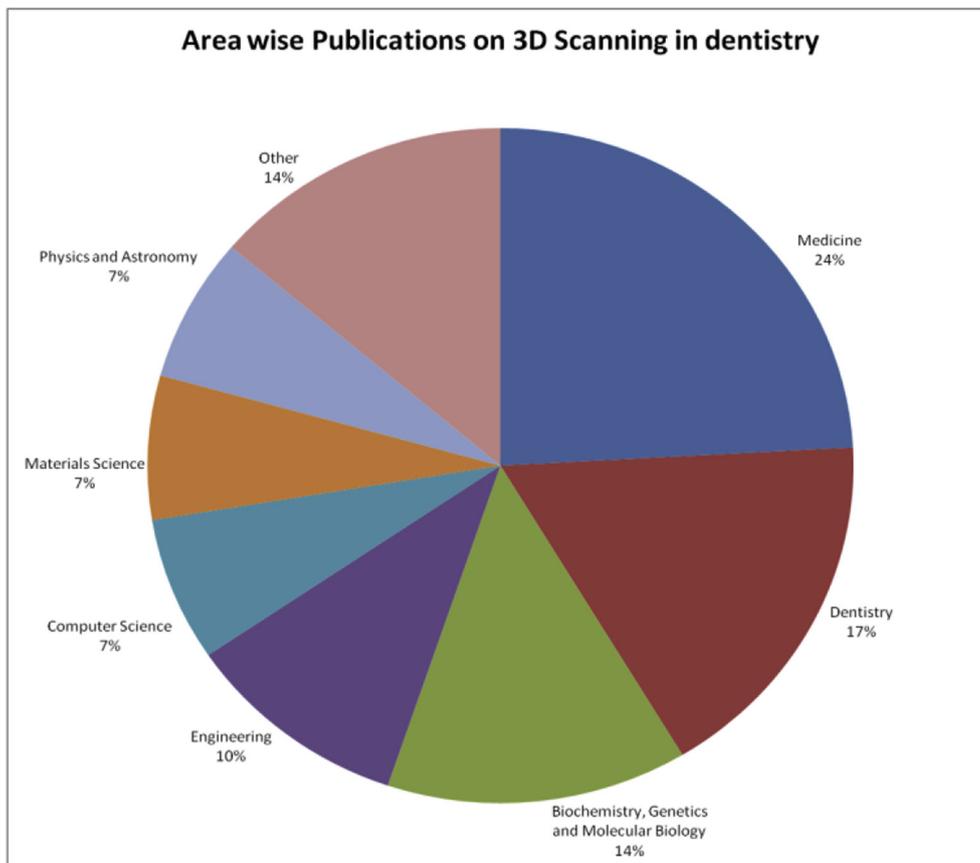

Fig. 2. 3 D scanning in dentistry: area-wise contributions (Source: Scopus).

Table 2
Steps to create 3D dental implant using a 3D scanning technique.

S No	Steps	Description	References
1	A physical model for scanning/input	• Developing a physical model, i.e. dentist model like teeth, jaw and associated parts • Create a reference model, and sometimes this model is also compared with another model, obtained through other CAD processes/scanning process • Preparing a dentist model well before the scanning	Hajeer et al., 2004[26]; Logozzo et al., 2014[27]
2	3D Scanning	• Dental model needs scanning in all directions such as front, back and sides with different sets of input parameters • The 3D scanner creates the resulting point clouds data by assembling different scans	Sakornwimon and Leevailoj 2017[28]; Londono et al., 2015[29]
3	Export data	• Export raw data into several types of useful files formats, such as STEP, IGES and STL formats • Mostly STL format is exported due to the universality of its use • It involves a surface triangle mesh	Javaid and Haleem 2017[3] Asquith and McIntyre, 2012[30]
4	Edit data	• In this step, data can be changed, edited and modified • Data is modified through different designing software and make changes as per requirement of the patient	Javaid and Haleem 2018[9]; Del Corso et al., 2009[31]
5	3D printing	• After modification in the data, a 3D solid object is fabricated from the 3D digital file by addition of materials layer by layer • It is a reliable method for reconstruction of precise dentist model with cost-effectiveness as compared to other traditional techniques	Javaid et al., 2015[32]; Kumar et al., 2015[33]; Haleem et al., 2016[34]
6	Post-processing and inspection	• It is necessary to go for post-processing of printed model due to low strength and surface finish • Inspection is also an essential step before actual implementation • Model printed by a 3D printing technology must be as per required quality and strength under a specific condition	Lee et al., 2014[35]; Kumar et al., 2016[36]

technologies. Table 2 discusses the various steps as used to create a 3D model contemporarily.

During scanning, some parameters are necessary to be kept stable such as temperature, humidity and lighting. It is also necessary to perform a verification/calibration of 3D scanner before measurement, or group of analysis.

8. Major applications of 3D scanning in dentistry

Dentist healthcare professional requires a digital replica of patient mouth for various reasons. Now 3D scanners are available to create digital dentistry. It is an automated process which takes the scan of whole patient mouth in few minutes. In dentistry, 3D scanning is an essential tool because plaster model of the patient's mouth or teeth has to be built quickly and use this model for treatment planning, diagnosis and appliance construction. By using 3D scanning technique, it re-creates a possible best fit model of the teeth, silicone maxillofacial prosthesis and ceramic crowns. It gave better accuracy and used in various applications in dentistry. (Please see Table 3).

3D scanning application helps dentist and surgeon to design and develop any implant and dental devices. In dentistry, it improves patient outcomes and used for preoperative planning, education, custom designing and make reliable operation. It provides a better understanding of surgeon and patient.

9. Discussion

3D scanning is an innovative technique towards customised designing of dental implants and other dental tools using different types of software. It efficiently designs/redesign any dental crowns, bridges, orthodontic braces and other devices and instruments as per patient requirement. The principle of a 3D scanning device is similar to that of a camera; here in this process, multiple images are combined to form a digital 3D model. This technology plays an essential role in research and development of dentistry implants and tools. Up-gradation in any dentistry model, tools and equipment are promising as per requirement of the dentist. It is quick scanning, and subsequent CAD modelling, compatibility to software analysis and integration to printing machine is wonderful which improves patient outcomes and overall reliability of the process. 3D scanning technologies easily help to recreate teeth of patients, jaws and other dental devices exact like an original. A surgeon

can update tools and implants any time in the digital file. It reduces operation time and provides better planning before surgery for the complicated procedure. It gives an efficient design for all oral health items as per human mouth shape and size. 3D scanned model used to train medical student by better demonstrate internal and external anatomy.

10. Future scope

This technology is already used in various fields of engineering, medicine and dentistry to produce accurate product/medical model. It can design highly accurate 3D digital model of patient teeth as well as mouth which is very much helpful for treatment planning. In future, it will create development in digital dentistry and become more common in this field. This technology gives an accurate result and is patient-friendly as compared to other scanning technologies. It is used effectively for clinical research and clinic-pathological correlation which can well couple with holographic and virtual technology. It improves communication between patient and dentist. It helps to solve primary requirements of complexity and customisation because patient data is differing from one another. Researcher and dentist will apply this technology to study patient's anatomy, reverse engineering and research purpose. This non-contact technology measures human structure and provides the best training for medical education. In future, it will become an excellent approach that captures accurate data of the physical model, and additive manufacturing technologies easily print this data in less time and cost.

11. Conclusion

3D scanning has extensive application in dentistry in which designing of personalised dentistry models, drill guides for dental implants are possible. It has vast application areas such as industries, defense, aerospace, art, medical to enhance the customisation and rapid production. Nowadays, it has various applications in the field of dentistry in daily life. The research is continuously increasing which brings a new revolution in dentistry. It has great potential to design and develop tools for dentist and surgeons. In upcoming years this technology will bring a more dental product for a dentistry lab. The dentist can take advantages of this technology for design and help for the replacement of teeth, crown, braces, dentures, veneers and aligner. It gives a better

Table 3
Applications of 3D scanning in dentistry.

S No	Applications	Description	References
1	Help to create teeth, denture, bridges and various other implants	• 3D scanners are used to create dental devices perfectly • Generate accurate digital data and recreation of teeth • By using this technology, 3D information is available digitally and can be updated any time • Help to create a complete set of denture that matches like an original	Andriessen et al., 2014[37]; Benic et al., 2015[38]; Lee et al., 2015[39]; Wismeijer et al., 2014[40]
2	Surgical planning	• A 3D digital dental model provides better planning before surgery which reduced operation time cost as well as risk • The surgeon can predict the problem and understand better for a complicated procedure	Lin et al., 2013[41]; Logozzo et al., 2011[42]
3	Innovation in dentistry	• This technology creates innovation in implants, devices, products, teeth, appliances and solves various issues in dentistry • It helps to provide the best advancement in dentistry to fulfil various updates requirements	Lowe 2009[43]; Singh et al., 2018[44]
4	Storage of patient data (reduce storage cost)	• The old part is stored in digital format and can be quickly retrieved to produce a dental product, moulds, tooling as and when required • It is accurate and fastest way to update features of old parts and dentistry tools • It makes innovative and up-to-date dental practice	Lin et al., 2015[45]s; Miyazaki et al., 2009[46]; Choi and Kim 2012[47]
5	Upgrades tools and equipment	• In dentistry one of the purposes of this technology is to design and upgrade tools and types of equipment • It easily upgrades and modifies various dental implant and dentistry tools	Brawek et al., 2013[48]; Nedelcu and Persson 2014[49]; An et al., 2014[50]; Kim et al., 2016[51]
6	Restore old part or devices (When no CAD data is available)	• Help in the manufacturing of correct teeth with correct alignment at an early stage • Scanned model shows the requirement of various corrections • The dentist can make innovative improvements in various devices which is better for the patient	Lee et al., 2013[52]; Haleem and Javaid 2018[53]; Patzelt et al., 2014[54]; Cuperus et al., 2012[55]
7	Research and development of implant	• A 3D scanner can easily undertake scanning of fossil teeth or mandibles to create anthropologists and archaeologist's research database • 3D scanner and designing software easily up-grade dentistry implants and other tools as per requirement which is helpful in research and development purpose	Naidu and Freer 2013[56]; Lee et al., 2008[57]; Abdel-Azim et al., 2015[58]; Javaid and Haleem 2018[59]
8	Designing of oral healthcare items	• Designing is done quickly for oral healthcare items such as toothbrushes, flossing devices as per the number of teeth and human mouths shape, a size that assure a comfortable and good fit for the general population • It fulfils the requirement of mass customisation and performs satisfactorily • It is time and cost saving method	Anh et al., 2016[60]; Mangano et al., 2017[61]; Kravitz et al., 2014[62]
9	Education and training	• 3D scanning technology provides a better demonstration of internal and external human anatomy structure rather than 2D pictures • Better illustration to the students for training purpose • It gives colour 3D digital models for teaching as well as in research purpose for medical/dental education • A better understanding of surgical procedure and problem	Kumar et al., 2018[63]; Marti et al., 2017[64]

understanding of complex pathology and anatomy of patients and is suitable for surgical training. The dentist can convert a new idea into a reality and save much time. By using this technology, there will be an improvement in the quality of life of the patient, and it will efficiently solve the problem in dentistry.

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