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History of and current situation regarding dental CAD/CAM systems and future perspectives

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ABSTRACT : The Dental CAD/CAM system has been in use for more than 30 years, and has been an indispensable tool for dental workflow. Before this practical system was in operation, it was necessary to develop computer technology in the handling of 3-dimensional data freely and to advance new dental materials. This trend will continue to expand in the future. Recently, optical impressions are taken instead of using impression materials against the background of great progress in sensor technology. Likewise, dental workflows that do not need plaster working models have become mainstream. In this paper, we outline the history and current trends of this technology, and describe prospects for the future.

Key Words : dental CAD/CAM system, intra-oral scanner, additive manufacturing (AM)

Introduction

1) History of dental CAD/CAM systems

Studies on dental CAD/CAM systems began more than 25 years ago, from the 1980s to 1990s, in Europe and the United States[1-11]. The first commercially available system was the CEREC system developed by Professor Werner H. Mörmann of Zurich University in Switzerland and SIEMENS AG of Germany. Studies were carried out in Europe to try to establish alternative treatments to the old amalgam filling method. Much interest was shown in the CEREC system, a system in which an inlay was milled out from a ceramic block in the clinic the patient was visiting and was set into the affected tooth on the same day, and clinics in Japan started using the system.

Application of the CEREC system was initially limited to ceramic inlays. In the procedure for producing a ceramic inlay, the measured shape of the cavity becomes the shape of the product. The areas requiring three-dimensional shape design were limited to only a small part of the whole area, *i.e.*, a small occlusal surface area and/or proximal surface area. It was therefore possible for the CAD/CAM system to be constructed as a compact system. The compact design of the system at that time led to its current success.

A very advanced feature of the CEREC system when it was first developed was the inclusion of an intraoral scanner in the system. We think that the intraoral scanner is a key feature for the analog-to-digital change in dental treatment.

Although the CEREC system could be used for the production of an inlay, it was difficult to construct producing crown and bridge, which requires capacity to freely design a three-dimensional crown form, *i.e.*, full occlusal proximal, labial (buccal) and lingual surfaces freely. At that time, the processing capacity of a computer (hardware) was not sufficient and the 3-dimensional library (software) had not been fully developed[12-18]. To overcome these problems, François Düret of the University of Southern California tried to construct a system for designing a crown shape with a wire frame on a general-purpose personal computer[2, 4].

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Dianne Rekow of the University of Minnesota in the United States was also making efforts to construct such a system[3, 8, 9]. Several groups in Japan, including Yoichi Uchiyama's group at Hokkaido University and Takashi Miyazaki's group at Showa University, were also conducting research and development in cooperation with companies[14-24]. Uchiyama's group carried out research coordinated by industry, academia and the government as part of a large-scale research and development project of NEDO (New Energy and Industrial Technology Development Organization). Research conducted by these groups resulted in systems becoming commercially available, but widespread use of the systems was not achieved at that time because of the high cost of the systems and lack of appropriate new materials.

2) Introduction of zirconia ceramic

All-ceramic crowns and bridges require many steps to make. A problem with conventional dental porcelain materials is that they are brittle and do not have sufficient strength for a crown prosthesis. Alumina porcelain, which appeared later, has greater strength, but its strength is still not sufficient for a bridge of molars. Alumina porcelain also has poor light permeability and its color is different from the color of teeth. Zirconia ceramic was newly approved for clinical use in Europe and the United States and began to be used for dentistry prior to its use in Japan. Although the initially developed zirconia ceramic material had difficulty in transmitting light, it has extremely high fracture toughness compared to that of conventional dental ceramic materials, and a sufficient strength of zirconia ceramic as a frame for a long-span bridge was achieved[25, 26]. However, a high sintering temperature of 1,350 to 1,500℃ is required for producing zirconia ceramic, and shrinkage of about 20% occurs during the sintering process. Therefore, it was not possible to cope with conventional manual work. It was therefore necessary to predict the amount of shrinkage during firing of zirconia ceramic and to mill a frame of about 20% larger in size. Calculation by a computer was used to compensate for the amount of shrinkage during firing. Utilization of a CAD/CAM system became indispensable to support this processing method and workflow. The development of dental CAD/CAM systems has advanced rapidly, mainly in Germany and the United States. A 3D model scanner and dental CAD/CAM system are now being used worldwide, and an all-ceramic crown bridge using a zirconia frame is popular now.

3) Coverage of CAD/CAM crowns by national health insurance in Japan

Due to efforts made by Mr. Uchiyama and Mr. Miyazaki and people who supported them, treatment using a "CAD/CAM crown" made from a hybrid resin block with a CAD/CAM system came to be covered by national health insurance in April 2014, and many people have been able to receive the benefits of this technology[27-30].

1. Components of the dental CAD/CAM system

The dental CAD/CAM system mainly consists of a scanner for measuring a three-dimensional shape, CAD software for designing a crown prosthesis, CAM software for generating NC data for processing, and a processing machine for producing an actual prosthesis from virtual digital data.

1) Three-dimensional scanner

In most cases, three-dimensional scanning is performed on plaster models for abutment teeth and dentition. Remarkable improvements have been made over the past few years in the performance of intraoral scanners, and their performance is now of a sufficiently high level for the scanners to be used clinically in cases of prosthodontics for several teeth[31, 32]. There are several modes for 3D scanners. When measuring a gypsum model, many systems project a light pattern such as a striped pattern onto the object and capture the three-dimensional shape by analyzing images taken by a CCD camera. In this mode, shape measurement would be possible with only one CCD camera if parameters such as the angle formed by the incident light and the CCD camera and the photographing magnification are known. Many devices have several built-in CCD cameras in order to capture the shape of the undercut portion that is in shadow and to perform measurements at high speed. In some cases, model capture is performed by rotating the stage at various angles. It is also possible to greatly increase the amount of information that can be acquired by using a multi-valued pattern with light having a multiple striped pattern. Speedy and accurate measurements can thus be performed. By scanning the plaster model to acquire three-dimensional shape data, it is possible to replace subsequent analog work by digital work. This workflow can be smoothly incorporated into conventional crown prosthetic treatment and dental laboratory work, and such a workflow is now being used worldwide due to reduction in the price of scanners.

Measurements using an intraoral scanner can be performed by performing triangulation with projection of a pattern of light as in the case of a model scanner, by performing confocal laser scanning or by performing active wavefront sampling using a wavefront sensor[33, 34]. These developments have been made possible by recent advances in sensor technology (miniaturization, high density, and high pixel count) and improvement in driving speed (clock frequency) of electronic circuits. Attention is currently focused only on direct and precise intraoral measurements of the three-dimensional shapes of abutment teeth and dentition. However, improvement in the scanning speed will probably become an important factor in the future. If scanning speed can be increased by 100 to 1,000 times, it will become possible to obtain data for eccentric movement of the lower jaw and contact sliding movement of a tooth.

2) Computer-aided Design (CAD) software

The shift to a digital workflow means that various work spaces are transferred from the real world to the virtual world managed by a computer. The design of three-dimensional shapes by CAD software is generally based on a combination of geometric shapes such as cubes and cylinders. Since the three-dimensional shapes can be represented by simple numerical values and mathematical expressions, the development of CAD software progressed to a level sufficient for practical applications even at the time when computing power was low[35-37].

However, when processing data for a living body, it is necessary to apply something more than a three-dimensional parametric space because the surface shape of human body assumes a free form[12]. A voxel model is suitable for storing data obtained from scanning by CT or MRI in a living body, but the volume of data increases with an increase in the number of voxels. Both of these design processes became possible with the development of parallel processing hardware that can perform huge calculations instantaneously and the development of basic software that can drive it. Technology of CAD software for designing an optimal occlusal surface configuration for each patient is important. However, CAD software that can be easily used by dental technicians, who are the main users, *i.e.*, software that enables design of crowns and bridges in a short time, is required.

One concern regarding CAD software is that manufacturers are advocating an "open system" and compatibility by "STL format" data. The STL format is a very simple data format represented by a triangular planar patch and its normal vector (Fig. 1). However, the STL format is originally a CAM format for stereolithography, not a CAD format. Therefore, it is not suitable for the design and editing of a three-dimensional shape. Generally, there are multiple standard data formats in three-dimensional CAD software. Most of them can handle and exchange free-form surface data such as data for NURBS (non-uniformed rational B spline curved surface) (Fig. 2). These data formats are widely used in various applications including industrial design

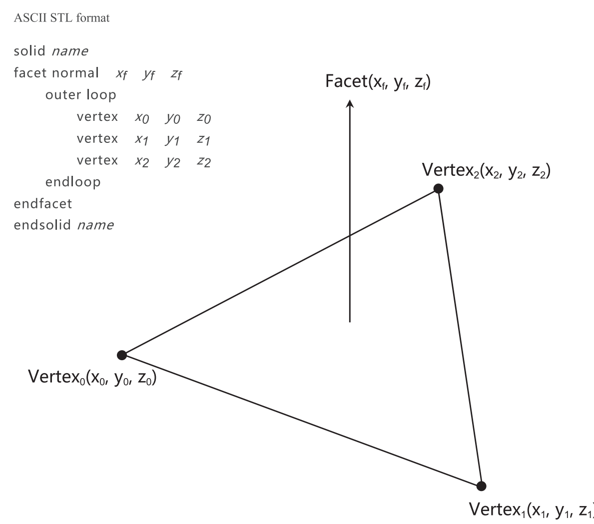

Fig. 1 STL format

$$S(u, v) = \sum_{i=1}^{k} \sum_{j=1}^{l} R_{i,j}(u, v) P_{i,j}$$

$$R_{i,j}(u, v) = \frac{N_{i,n}(u) N_{j,m}(v) w_{i,j}}{\sum_{p=1}^{k} \sum_{q=1}^{l} N_{p,n}(u) N_{q,m}(v) w_{p,q}}$$

$S(u, v)$: Surface
$R_{i,j}(u, v)$: Rational basis function
$N_{i,j}(u)$: Basis function
$w_{i,j}$: Weight parameter
$P_{i,j}$: Control point ($0 \leqq i \leqq n$, $0 \leqq j \leqq m$)

Fig. 2 Definition formula of NURBS

Table. 1 Example of standard CAD file format

Format	License Source
AutoCAD DXF (Drawing eXchange Format) AutoCAD DWG (drawing) format	Autodesk Inc.
IGES (Initial Graphics Exchange Specification) format	ANSI American National Standards Institute
STEP (STandard for the Exchange of Product model data / ISO 10303)	International Organization for Standardization

and CG animation (Table 1). In the development of dental CAD software, wide compatibility by supporting these data formats is required.

3) Computer-aided Manufacturing (CAM) software

CAM software is software that generates driving data for a processing machine. The method used for data processing naturally depends on the type of processing apparatus, but the most common method currently used is milling. In a milling process, a ball end mill with a hemispherical tip is generally used as a processing tool. The processing method depends on how the ball end mill is applied to the milling block, and a 3-axis processing method or a 5-axis processing method is used. In 3-axis machining, the milling tool is driven by parallel movement with respect to three orthogonal axes, XYZ axes. In 5-axis machining, the milling tool is driven by a total of five types of motion, XYZ translation in three orthogonal axes and rotational movement around the XY axes. Five-axis machining is necessary for machining complex shapes including undercuts. Considerable technical development will be required to optimize the trajectory (drive data / NC [Numerical Control] data / cutter pass, etc.) of the tip of the ball end mill in a 5-axis processing machine. An optimized tool path, by which the processing is completed in the minimum time and the finish quality is good, is required to improve work efficiency.

4) Processing machine

As mentioned above, 5-axis milling machines are used in almost all cases as processing machines for CAM systems. However, various processing methods, including forging (a method of forming a shape by tapping), casting, injection molding, electric discharge machining, and rapid prototyping, have been tested. Among the various methods that have been tested, attention has been focused on milling technology and 3D printing technology, for which the name has changed from rapid prototyping to additive manufacturing. Many new technologies have been developed, particularly in Japan and Germany, for a milling process. An advantage of milling is that it is possible to produce an individually optimized form from previously prepared homogeneous materials. However, milling also has the following disadvantages : some materials cannot be milled, a long time is needed for the processing, some shapes cannot be processed due to tool interference, and much of the material is wasted. Three-dimensional printing technology, which has received much attention in recent years, has undergone many developments in both the US and Japan, but further developments are still required[38, 39]. Seven methods are used in additive manufacturing technology (Table 2), and four of those methods are used in the field of medicine including dentistry[40-42]. The four methods are 1) the “vat photopolymerization” method, in which a photo-curable liquid resin in a tank is selectively cured with an ultraviolet laser, 2) the “material extrusion” method, in which a flowable material is extruded from a print nozzle and deposited, 3) the “powder bed fusion” method, in which powder is laid and melt-bonded by selective high-energy irradiation and 4) the “binder jetting” method, in which powder is laid and a liquid binder is selectively jetted and solidified. Some of these methods have already been used in clinical applications. However, the methods are not being used widely because of the high cost of equipment and the requirement of knowledge regarding maintenance and management. Reduction in the cost of milling by mass production is difficult. However, considerable reduction in cost would be possible by using 3D printing technology. Moreover, 3D printing enables the manufacture of FGMs (functionally graded materials), which cannot be manufactured by milling. Thus, it is expected that 3D printing will become one of the main manufacturing methods in the future.

Table. 2 Seven methods of Additive Manufacturing

Method	Overview	Materials
Sheet Lamination	Stack a sheet material while cutting it with a laser or knife.	Paper, Resin, Metal
Vat Photopolymerization	Selective laser curing photo-curable resin layer by layer	Photo-curable Resin, Ceramic
Material Extrusion	Extrude resin melted by heating from the nozzle	Thermoplastic Resin
Binder Jetting	Liquid binder is jetted from nozzle onto powder materials	Resin, Metal, Sand, Plaster, Ceramic
Material Jetting	Selective jetting liquid materials from nozzle	Photo-curable Resin, Wax
Powder Bed Fusion	Selective melting and bonding powder materials with laser or electron beam	Resin, Metal, Ceramic
Direct Energy Deposition	Supply powder materials and laser from nozzle simultaneously, and selective melting and bonding	Metal

5) Materials

Although all materials that can be cut can be processed, it is necessary to consider the running cost due to wear of the cutting tool, and practical options therefore become limited. Advances have been made in the development of resin-based materials such as acrylic, epoxy, nylon and amide and the development of metallic materials such as copper, iron, titanium, nickel and cobalt for additive manufacturing (3D printing) technology. For dental use, cobalt chromium alloy has been used as a metal frame of a porcelain-fused metal crown and for a partial denture, and acrylic resin is being used for manufacturing dentures. In the future, if technologies are established for the use of super engineering plastics such as PEEK / PEKK (polyether ether ketone / polyether ketone ketone) and other new materials such as carbon-type and cellulose-type nanotechnology fibers and ceramic materials, these materials could be used for the production of various types of crowns and bridges. However, studies focusing on these materials have not yet been carried out.

2. Current problems and future prospects

Impression taking is one of the most difficult and important tasks in the flow of conventional dental treatment. If the marginal gingivae have been maintained in a good condition, the difficulty level of impression work is slightly diminished. However, the difficulty level is greatly affected by many factors including the patient's general health condition, the degree of oral cleaning before coming to the clinic, and the position of the marginal line after removal of the affected tooth. Taking impressions is very difficult if the gingiva easily bleed. The intraoral scanner is an epoch-making technology that greatly reduces the burden of impression taking. However, an intraoral scanner cannot scan to the margin line hidden behind the marginal gingiva. Therefore, it is necessary to make sure the margin line of the abutment teeth is visible. When taking an impression using a conventional impression material in cases in which the marginal line cannot be seen directly because the marginal gingiva is overhanging, if gingival retraction and hemostasis are sufficiently performed and an impression material can be put into the gingival pocket, the shape of the marginal line can be transcribed. However, a shape cannot be measured by an intraoral scanner if it is not directly visible. If this problem can be solved, we may be completely free from impression taking of crowns and bridges as we are currently doing.

Another problem is mandibular jaw movement. In the currently available CAD / CAM systems, it is possible in principle to utilize data of mandibular jaw movement, but it is difficult in practice to obtain motion data. Therefore, shape design by the CAD is done in a static state without considering contact sliding movements of the upper and lower teeth, and technicians perform manual adjustments to the model after milling with the CAM. Even in the more advanced CAD system, a virtual articulator is implemented into CAD software to simulate a conventional semi-regulating articulator. It is therefore impossible to design an optimal functional occlusal surface configuration for each individual patient. Movement, which is a continuous event in the analog world, is represented by a series of stationary states with short time intervals in the digital world. Therefore, if shape measurement by an intraoral scanner can be performed at ultrahigh speed, a series of states in which the upper and lower teeth slide in contact can be regarded as a record of the positional relationship between the upper and lower jaws, and the occlusal contact state of each patient can be simulated by a CAD system without a virtual articulator. This would become possible if a scan speed of about 100 to 1,000 times the speed of currently available scanners is achieved. Scan speed depends on many factors including the output speed of image data from the image sensor, the bandwidth and driving speed of the data transfer bus in the signal line, and the processing speed of the large amount of read-out data. However, considering the development of television technology aiming for 4K to 8K and the development of video technology typified by game machines and CG / VR (computer graphics / virtual reality), it is reasonable to say that the elemental technologies that are needed for increasing scan speed are already available. It will be necessary to take measures to successfully apply these elemental technologies to the field of dentistry. The use of new materials is also an important issue. It is expected that newly developed CAD software in the future will enable almost automatic design of an optimal occlusal surface form for each patient.

Conclusion

A paper entitled "THE FUTURE OF EMPLOYMENT : HOW SUSCEPTIBLE ARE JOBS TO COMPUTERISATION?" by Michael A. Osborne *et al*., who were conducting research in the field of machine learning in Oxford University's Faculty of Engineering, was published in 2013. It was stated in their paper that advances in computer-related technologies such as artificial intelligence and robots will result in much of the work that is done manually being replaced in the near future by machines and digital equipment[43]. Their paper received worldwide attention. This possibility is often discussed as a shocking scenario of current jobs disappearing and employment opportunities being lost. However, the positive effect of technological innovation resulting from digitalization, that is, that manual workload will be reduced and people can concentrate on more essential things, should be considered. In the field of dentistry, the change to digital technology will result in reduction in the burden of having to improve procedures such as preparation for abutment tooth, impression taking, and maxillomandibular registration. It is expected that the change to digital technology in dentistry will enable determination of the state of occlusion that each patient should have.

References

1) Fujita T, Yamamura M, Watanabe H et. al. : Preliminary report on construction of prosthetic restorations by means of computer aided design (CAD) and numerically controlled (NC) machine tools. Bull Kanagawa Dent Coll 12 : 75-77, 1984.
2) Duret F. : Toward a new symbolism in the fabrication of prosthetic design. Cah Prothese 13 : 65-71, 1985.
3) Rekow ED. : Computer-aided design and manufacturing in dentistry : A review of the state of the art. J Prosthet Dent 58 : 512-516, 1987.
4) Duret F, Blouin JL, Duret B. : CAD-CAM in dentistry. J Am Dent Assoc 117 : 715-720, 1988.
5) Mörmann WH., Brandestini F., Lutz F., Barbakow F. : Chair side computer aided direct ceramic inlays. Quintessence Int 20 : 329-339, 1989.
6) Mörmann W, Brandestini M : Die CEREC Computer Reconstruction: Inlays, Inlays, und Veneers. Berlin : Quintessenz Verlags-GmbH, 1989.
7) Kunzelmann, KH and Hickel, R. : Zur Präzision des Cerec-Systems : die Schleifeinheit. Dtsch Zahnärgtlz. 45 : 277-280. 1990
8) Rekow D. : Dental CAD-CAM Systems: What is the state of the art. J Prosthet Dent 122 : 43-48, 1991.
9) Rekow ED, Thompson VP, Yang HS. : Margin fit of CAD-CAM produced crowns. J Dent Res 70 : 715-720, 1991.
10) Isenberg BP., Essig ME., Leinfelder KF., Mueninfhoff LA. : Clinical evaluation of CEREC CAD/CAM restorations emphasizing marginal integrity. IADR 70 : 1345, 1991.
11) Mörmann W., Krejci I. : Computer-designed inlays after 5 years in situ: clinical performance and scanning electron microscopic evaluation. Quintessence Int 23 :109, 1992.
12) Gerald Farin. : Curves and Surfaces for Computer Aided Geometric Design. A Practical Guide Second Edition, Academic Press, Inc. 1990.
13 Jayaram K.U, Gabor T.H. : 3D Imaging in Medicine. SECOND EDITION. CRC Press LLC. Florida, USA, 2000.
14) Inamochi T : “Studies on the Electric Discharge Machining of Titanium (Part 1) Electric Discharge Machining Properties of Titanium” JJ Dent Mat. 7(4) : 606-621, 1988
15) Inamochi T : “Studies on the Electric Discharge Machining of Titanium (Part 2) Application to Dental Prosthetic Works” JJ Dent Mat. 7(4) : 622-632, 1988
16) Miyazaki T, Inamochi T, Kitamura M, Suzuki E, Miyaji T : “Development of the New Prosthetic work for the Next Generation ; Application of the Ultrafine Machining technique (Electric Discharge Machining)” QE. 8(2) : 127-138, 1989
17) Tsutsumi S, Fukuda S, Tani Y : 3-D image measurements of teeth and alveolar ridge. J Dent Res 68(Sp.) : 924, 1989.
18) Uchiyama Y : Qualitative Advancement in Dentistry by CAD/CAM. Journal of Japan Ergonomics Society 26 : 20-21, 1990. (printed in Japanese)
19) Kimura H, Sohmura T, Watanebe T : Three-dimensional Shape Measurement of Teeth (Part 6) : Measurement of Tooth Model by Tilting Method by Means of the Double Sensor Laser Displacement Meter, and the Simulation of Occlusion. J. J. Dent. Mater 9 : 679-686, 1990. (printed in Japanese)
20) Miyazaki T, Hotta Y, Suzuki E, Miyaji T, Takahashi H, Fufuya R, Kawawa T : “An Approach to the Dental CAD/CAM Using the Electric Discharge Machining (Part 1), Measurement of Coronal Figure, Computer Graphics, and CAD Procedure”. J. Showa Univ. Dent. Soc.11. 65-69, 1991. (printed in Japanese)
21) Uchiyama Y, Saitoh H, Ueda Y. : CAD/CAM for crown fabrication. 5th Meeting of the International College of Prosthodontists Program Abstracts : 19, 1993.
22) Ueda Y : A Study of Computer Aided Design System for Tooth Crown Form. Jpn Prosthodont Soc, 40 : 993-1003, 1996. (printed in Japanese)
23) Hikita K : A Study on Three-Dimensional Measurement and Restoration of Tooth Crown-Form (by CAD/

CAM). J Jpn Prosthodont. Soc., 41 : 804-813, 1997. (printed in Japanese)

24) Miyazaki T, Hotta Y, Kunii J, Tamaki Y. : A review of dental CAD/CAM : current status and future perspectives from 20 years of experience. Dent Mater J, 28(1) : 44-56, 2009.

25) Hotta Y, Miyazaki T : Current Status and Future Perspectives of Dental CAD/CAM Systems Available for the Fabrication of Crown-bridge Restorations. Ann Jpn Prosthodont Soc 3 : 1-11, 2011. (printed in Japanese)

26) Miyazaki T, Hotta Y : CAD/CAM systems available for the fabrication of crown and bridge restorations. Australian Dental Journal, 56(s1) : 97-106, 2011.

27) Nakamura T : All Ceramic Restoration in the Digital Age. Ann Jpn Prosthodont Soc 4 : 132-139, 2012. (printed in Japanese)

28) Tanaka S, Tachi K, Miyauchi T, Kamimura E, Baba K : Digital Dentistry Changes the Prosthodontics. Dental Medicine Research 3(32) : 215-220, 2013.

29) Miyazaki T : Advanced medical treatment using digital technologies. JJ Dent Mat. 33(6) : 503-506, 2014. (printed in Japanese)

30) Shinya A, Miura S, Koizumi H, Hikita K, Mine A : Current status and future prospect of CAD/CAM composite crown. Ann Jpn Prosthodont Soc 9 : 1-15, 2017. (printed in Japanese)

31) Paul F : Technology INTEGRATION. New Changes in CAD/CAM : Part 1, INSIDE DENTISTRY-FEBRUARY, 84-87, 2007.

32) Shembesh, M., Ali, A., Finkelman, M., Weber, H.-P. and Zandparsa, R. : An In Vitro Comparison of the Marginal Adaptation Accuracy of CAD/CAM Restorations Using Different Impression Systems. J Prosthodont, DOI : 10.1111/jopr. 12446, 2016.

33) Wicher J. van der Meer, Frank S. Andriessen, Daniel Wismeijer, Yijin Ren : Application of Intra-Oral Dental Scanners in the Digital Workflow of Implantology. PLoSONE 7(8) : 2012.

34) Güth JF, Edelhoff D, Schweiger J, Keul C. : A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clinical Oral Investigations, 20(7) :1487-94, 2016.

35) exocad DentalCAD : https://exocad.com/our-products/exocad-dentalcad/

36) 3shape Dental System : http://www.3shape.com/new-products/dental-labs/cad-software

37) dental wings : http://www.dentalwings.com/products/software/

38) Kodama H : Automatic method for fabricating a threedimensional plastic model with photo hardening polymer. Review of Scientific Instruments 52 : 1770, 1981.

39) Herbert A.J : Solid object generation. Journal of Applied Photographic Engineering, 8 : 185-188, 1982.

40) Committee F42 on Additive Manufacturing Technologies : https://www.astm.org/COMMITTEE/F42.htm

41) Standard Terminology for Additive Manufacturing Technologies : http://web.mit.edu/2.810/www/files/readings/AdditiveManufacturingTerminology.pdf

42) Ian G, David R, Brent S : Additive Manufacturing Technologies : 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing. Springer; 2nd ed. 2014.

43) Carl B.F, Michael A.O : THE FUTURE OF EMPLOYMENT : HOW SUSCEPTIBLE ARE JOBS TO COMPUTERISATION?, Working Paper, The Oxford Martin Programme on Technology and Employment, September 17, 2013. (http://www.robots.ox.ac.uk/~mosb/)