Original Article

INTRAORAL SCANS FOR CAD/CAM APPLICATION

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ABSTRACT

Introduction: There is no doubt the world of dentistry is rapidly changing. Digital innovations are replacing our traditional techniques. Dentists need to keep up with the speed of today's ever changing digital world.

The aim of the paper is to educate about the concept of digital dentistry, its advantages and limitations, and to provide an overview of digital impression taking procedures and the digital workflow for CAD/CAM application.

Materials and methods: The Department of Prosthodontics, Faculty of Dentistry, Semmelweis University (SU) published a series of articles in Hungarian dental paper as part of the continuing education program to educate Hungarian dentists at the postgraduate level. Digital technologies and their novel materials are also introduced into the SU undergraduate dental curricula. A Bachelor of Science (BSc) digital dental designer training program is also aimed at the Faculty of Dentistry SU in cooperation with the Neumann University of Technology and Economics to modernizate the classic profession of dental technician. This paper gives a summary of the basic knowledge published in digital dentistry series.

Results: The CAD/CAM technology offers a quick and comfortable experience to the patients and an efficient workflow to the dentist and dental technicians. The learning curve is steep to adopt that new technology both in the dental office and on the laboratory side. Educated dental students and digital designers have the potential to keep pace with the digital era change.

Keywords: CAD/CAM, scanner, intraoral, workflow, dental impression technics.

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1. Introduction

The widespread use of digital technology is to transform our everyday life: computers and digital devices offer an easier, faster and more economical alternative to conventional methods. The digital revolution also has an impact on dental procedures. It is a fact that dentistry changes and undergoes dramatic developments. In order to meet the patients' requirements, it is important to expand our dental knowledge to digital technologies.

Present day dental students grow up in a world of digital innovation and technology, so the need to include digital technology in their curriculum is evident for them [1]. However the dental curriculum has not really changed in 50 years. It has not been revised. Much has been added to what dentists must know, considering digital technology, there are all those new technologies, new CAD/CAM materials etc. but the curriculum has not been changed [2]. Most practicing dentists received their professional training before the advent of the digital dental technology. Once they become interested in the new technologies and in developing new skills they demand continuing education courses. There is a severe need to include digital dentistry in the undergraduate and postgraduate education programs. If digital technologies and their novel materials are not introduced into the dental curricula dentists and technicians will not fully understand the range of new technologies available to them and will not be able to make informed decisions regarding the most appropriate techniques, systems or materials [1]. Chatham et al. surveyed the undergraduate curricula of the UK dental schools in 2014 to determine the degree to which digital dental technologies have been introduced. Sixteen schools were surveyed and 11 replied. 55% of those schools did teach digital dental technology, 50% gave lectures or demonstrations while the other 50% allowed practical involvement by the student. Seventy-three percent of the schools that replied had dental laboratories using some, but not all the digital dental technology techniques [1].

1.1. Aim

The aim of this paper is basic digital education. To discuss the concept of digital dentistry, its advantages and limitations, and to provide an overview of digital impression-taking procedures, to clarify the basic steps of the digital workflow, to introduce the direct method of intraoral scanning to construct a virtual cast for CAD/CAM application. The purpose of the paper also includes clarifying the difference between chairside and labside systems, discuss the features of intraoral impression-taking such as accuracy, the time factor and the patient's subjective comfort, to present comparative data on the precision of digital impressions made by intraoral scanners to laboratory scanning of conventional casts and to compare the traditional impression-taking method to the digital one and provide a short summary on the advantages and difficulties of the scanning procedure.

2. Material and methods

The Department of Prosthodontics, Faculty of Dentistry, Semmelweis University has been working with digital impression-taking systems since 2011. Digital technologies and their novel materials have been introduced into the department's undergraduate dental curricula. A Bachelor of Science digital dental designer training program is also aimed at the Faculty of Dentistry SU in cooperation with the Neumann University of Technology and Economics to modernizate the classic profession of dental technician. A series of articles has been published in the Hungarian dental paper in 2017 as part of the continuing education program to educate Hungarian dentists about digital dentistry. This paper gives a summary of the digital dentistry series.

3. Results

In 2018 all four Hungarian dental schools teach digital technology, they give lectures and demostrations and 50% have also practical training. All four dental laboratories of those schools use some digital techniques (Fig. 1). Dental technology educational programs are faced with serious challenges, including rapid changes in technology, inadequate funding for educational programs, and the need to develop curricula that reflect current industry needs [3]. The high cost to purchase equipment and the investment of time and expense in staff training encourages non-university educational systems and trainings.

Manufacturers and commercial dental laboratories offer a selection of continuing education courses for international dentists. Some courses are accredited by universities and the participants are awarded certificates and European Credit Transfer System (ECTS) credits [4]. Online knowledge centers and webinars provided by manufacturers offer promising new opportunity for self-education [5].

Digital technology introduced new nomenclature for dental procedures: digital workflow, CAD/CAM systems, indirect CAD/CAM impression technique, direct CAD/CAM impression technique, digital impressions, virtual casts, intraoral scanners, close or open systems, charside or labside systems. These elements are drafted in italics in the following text.

3.1. Digital workflow

3.1.1. Indirect CAD/CAM method

The *digital workflow* starts with a device which is suitable for mapping real forms. *Indirect CAD/CAM method* is built on conventional impressions. The *virtual cast* is created by digitizing the gypsum cast (or the conventional impression) with a laboratory scanner [6] (Fig. 2). The virtual cast is a realistic, colorful digital model of the patient's oral cavity. This method has some distorting effects enclosed: conditions of impression-taking, material properties of alginate, silicone or gypsum (shrinkage of impression material, dilation or shrinkage of gypsum) and sectioning of casts. Furthermore, the laboratory scanner has some degree of distortion.

The laboratory scanner creates a 3-dimensional set of points based on information of the sectioned cast.

Figure 1. Dental students practice digital impression taking at the Department of Prosthodontics of Semmelweis University, Budapest.

Figure 2. Laboratory scanner creates a 3-dimensional set of points by information of sectioned cast or impression.

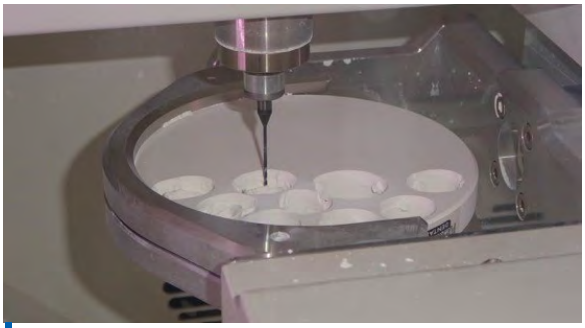

Figure 3. CAM (Computer-Aided Manufacturing) machine milled crowns from zirconia block.

The computer makes the virtual cast that serves *as basis for CAD/CAM workflow*. During CAD (Computer-Aided Design) the dental technician designs dental restorations, most often crowns, veneers, inlays or onlays and bridges. The CAD software enables the technician to design the framework of the restorations or the anatomical, final form. Applying CAM (Computer-Aided Manufacturing) the restorations are milled from solid blocks with dental milling CNC machines (Fig. 3). There are different types of materials to mill: ceramics, zirconia, PMMA, metal alloys or titanium.

3.1.2. Direct CAD/CAM method

The *Direct CAD/CAM method* means that the digital

data set is created by intraoral scanning. Intraoral scanners are intraoral devices for capturing direct optical impressions [6] (Fig. 4). *Intraoral scanners* are based on different data capture principles: confocal laser technology, confocal microscopy, triangulation, wavefront sampling, multiscan imaging, stereophotogrammetic video, accordion fringe interferometry [7,8].

It is important that the user takes digital impressions according to the manufacturer's instructions. This method can eliminate many inaccuracies derived from indirect CAD/CAM impression process. However, the traditional principles of the impression-taking procedure are still alive, soft tissue control and isolation remain basic principles. The scanning process ends with biterecord. There are intraoral scanners which can also determine the tooth-color.

The next step following the digital impression-taking procedure is to evaluate the quality of the virtual cast (Fig. 5). Inaccuracies can be eliminated by the dentist directly chairside within this step. The occlusal and axial reduction, the insertion direction can be observed on the computer screen with built in tools of software. The margin line can also be checked enlarged by the software.

Any imperfections of the virtual cast can be corrected without the need to retake the whole impression. Additional images of the areas of interest can be added to previous scan. When satisfied with the impression and resulting virtual cast, it is sent to laboratory with the digital worksheet via e-mail.

There are *open and closed dental CAD/CAM systems*. Closed systems' files can be opened by the manufacturer's CAD software only. Closed systems are CEREC AC and E4D systems. Most intraoral scanners work with an open system and they are compatible with several types of CAD softwers and milling machines (for example 3Shape TRIOS, Planmeca PlanScan, CEREC Omnicam, iTero Element, Carestream CS 3500, 3M True Definition, GC Aadva, DWIO Dental Wings, KaVo Lythos, Dentium Rainbow, Zfx IntraScan, MFI Condor IOS, etc) (7).

3.2. Direct CAD/CAM workflow

3.2.1. Labside system

The labside workflow of CAD/CAM technology means The labside workflow of CAD/CAM technology means that the dental technician processes data coming from the dental office. The technician performs the preparatory work on the virtual cast, model occlusion with CAD software and design restoration on the computer screen (Fig. 6).

The technician sets the margin line and the space for the cement. After that the framework or the full-contour restoration is designed. The anatomical occlusion surface and contour of the teeth can be made individually. The software contains the color of the restoration, so the suitable block is chosen for the milling. Digital planning does not exclude model making. From the digital data a polimer model can be made by milling, 3D printing or with stereolithography (SLA) [9]. The final restoration can be checked on this model (Figs. 7, 8).

Another option of the computer-assisted production is centralised production in a milling centre. In this variation, it is possible for the local laboratory to design

Figure 4. Trios intraoral captures optical impressions of the prepared teeth for the direct CAD/CAM method.

Figure 5. Full arch virtual casts in ICP position on computer screen after scanning.

Figure 6. Dental technician designs restoration on computer screen with CAD software.

the restoration, then data sets are sent for milling to the centre. Procera is a well-known example for milling centre. It is specialised for milling technically sensitive materials like high strength ceramics and titanium (Figs. 9, 10).

3.2.2. Chairside systems

We must not forget that initially intraoral scanners were developed for chairside solutions (CEREC). The main

idea was to make restorations without the need for dental laboratory. A chairside system means that every step of the workflow is in the hands of the dentist. Digital impressions are taken in the dental office with an intraoral scanner, designing the restoration is done chairside and even the milling and finishing is done in the office. Its great advantage is that it offers One Day Dentistry. Inlays, onlays, solo crowns can be made for patients within a few hours. Monoblocks restorations are milled with the CAM unit, which need small adjustments (staining, polishing, sintering) before cementation.

The main difference between those restorations milled by labside and chairside systems are the extension and the materials used. Chairside systems are made for solo restorations as mentioned before (veneers, crowns, inlays, onlays, small full contours), and temporaries. Labside milling in the dental laboratory or in the milling centres offers you more options due to the precision of 5-axis milling and high-strength materials, labside offers extended prosthetic appliances.

4. Discussion

4.1. Features of taking digital impressions - accuracy, time factor, patient's comfort

There are numerous factors that can easily describe the clinical use of the digital impression procedure. The investigation of some of these factors can be measured objectively, for example accuracy and scanning time. This is a well-researched area in literature. Other features of intraoral scanners can be described with subjective parameters for example patient's comfort and dentist's satisfaction.

4.1.1. Accuracy of digital impressions

The fit of the final restoration depends on the quality of the impression, therefore accuracy of intraoral scanners is one of the most important features. Accuracy consists of trueness and precision. Trueness describes how close our data are to the original true value. Precision shows the relative deviation of the repeated measurements [10] (Fig. 11).

In a blind study, crowns developed using intraoral scanning technology were preferred over crowns generated using conventional impressions and criteria of marginal fit, contacts, occlusion, and time of adjustment in nearly 70% of cases [11]. It was found that digital quadrant impression methods achieve a level of precision, comparable to the conventional impression techniques (precision ranged from 18.8 to 58.5 µm). However, there are significant differences in terms of absolute values and deviation pattern [12].

The direct digitalisation with Lava C.O.S. showed statistically significantly higher accuracy compared to the conventional procedure of impression-taking and indirect digitalisation when datasets were generated and superimposed by a best fit algorithm. It could be shown that direct digitalisation accomplished the most accurate results, followed by digitized polyether impression, and indirect digitalisation [13].

According to a study in 2015 the following scanners were found acceptable in clinical practice when

Figure 7. Polymer model made by 3D printing from digital data.

Figure 8. Polymer models are printed with pins holding the ICP position and mounted on an adjustable articulator for veneering.

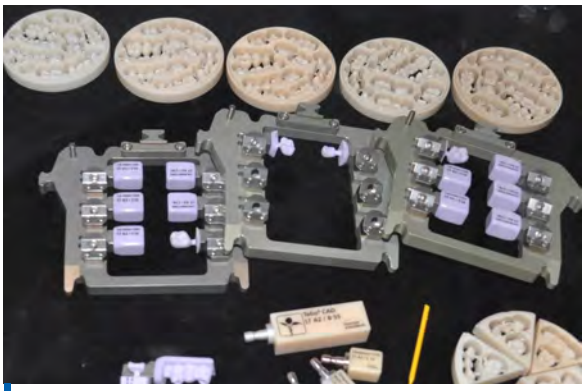

Figure 9. CAM/Computer Assisted Manufacturing: Blocks for zirconium-dioxide frameworks, lithium disilicate monolithic restorations and PMMA temporary restorations.

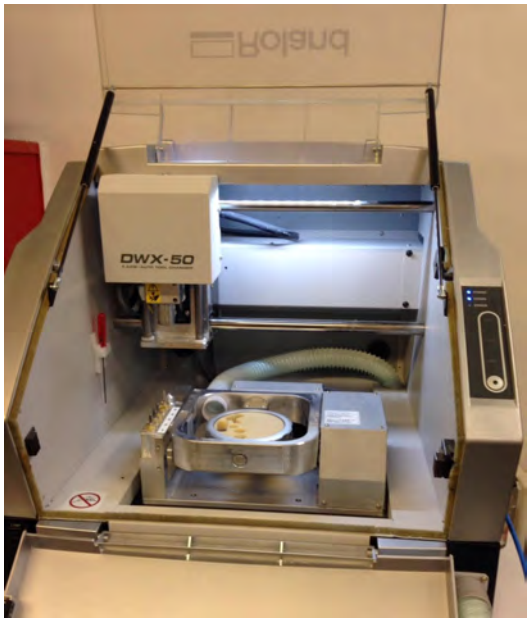

Figure 10. PMMA block manufactured in Roland DG DWX-50 milling machine. Advantage of PMMA temporary restorations fabricated by CAD/CAM technology is that they last long. Polymer's resistancy is much better than temporary materials used for conventional chairside technique.

CEREC, TRIOS) were made from a PMMA model for comparison [17] (Fig. 12).

4.1.2. Time efficiency (factor) of digital impressions

We have found numerous studies comparing the time needed for digital and conventional impression-taking techniques. When investigating the whole treatment time an average of 260 s is needed for a digital impression and 620 s for a conventional one. Bite registration with intraoral scanner took five times less than with the conventional technique [18].

Although scanning time extends when there are abutment teeth in the arch. Scanning 1 abutment is 23 minutes, 2 abutments 22 minutes and the whole arch is 13 minutes faster than conventional impression-taking. As the number of prepared teeth increases, the time of the intraoral scanning gets closer to the conventional impression-taking time. In these studies participants had experience in taking conventional impressions [19].

In Lee and Galucci's study dental students had no previous experience on taking impressions. Intraoral scanning took half the time of the conventional technique. Consequently, the study shows that without experience intraoral scanning is still a time saving technique. It seems that digital technology reduces patients' time spent in the dental office [20].

4.1.3. Evaluation of the digital impression-taking procedure based on the dentist's and the patient's subjective comfort

In 2016 Joda et al. investigated digital and conventional implant impression procedures. They found the usability and the efficiency of intraoral scanners more favourable by students (88%) and dentists (64%) compared to conventional methods [21].

According the previous studies patients prefer digital impressions to conventional ones. During conventional impressions patients reported breathing difficulties and they felt vulnerable, especially when upper impressions were taken. They were afraid of repeating conventional impressions rather than repeating digital ones [22].

Overall both dentists and the patients found it less stressful when impressions were taken digitally.

4.2. Intraoral scanning possibilities; advantages and difficulties

In the next session we would like to introduce the features of the new technology, which can be a benefit or an initial difficulty when we use an intraoral scanner [23].

4.2.1. Difficulties of intraoral scanning

Learning the process of intraoral scanning is not an easy task, it is important to follow the instructions given by the manufacturers. Digital impression taking is very different from conventional impression procedure.

During scanning as the scanner-head goes above the surface of the tooth the software adds new data to the images that have already been taken. The inappropriate use leads to insufficient or inaccurate virtual model. For implant scanning scan bodies are used, which are supported by the manufacturers (Fig. 13).

These scan bodies should be compatible with the

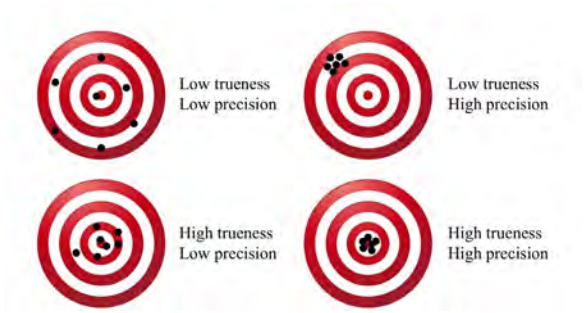

Figure 11. Fit of the final restoration depends on the quality of the impression. Accuracy consists of trueness and precision. Trueness shows how close is our data to the original true value. Precision shows the relative deviation of repeated measurements.

Figure 12. Less time is needed for a full arch intraoral scan compared to the conventional impression taking procedure.

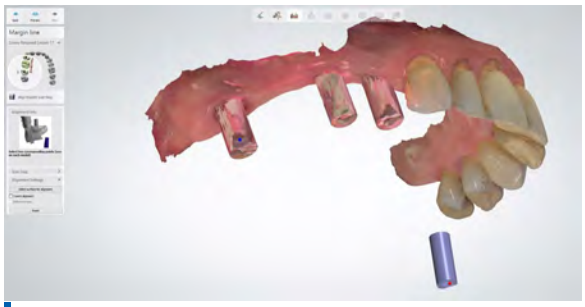

Figure 13. Scan bodies are used for implant scanning, they provide the necessary information for designing the prosthetic appliance.

CAD software in order to plan the digital prosthetic appliance. Manufacturers have already faced the need to start production of hybrid scan bodies, which are compatible with different systems.

If we are not properly informed about the scanners' features prior to the purchase, it may be an unpleasant surprise that some companies charge a data management fee. In such a case, after scanning the data, it is entered into the cloud operated by the company, from which it can only be sent to the laboratory after payment of the fee. However, most manufacturers provide an open system, which allows to export the STL files for free.

Limitation of intraoral scanners is that they are very expensive, however the cost of equipment is expected

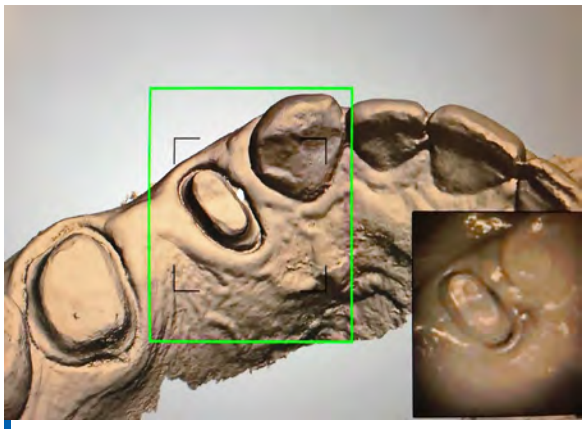

Figure 14. When digital impression taken, the virtual model is appearing continuously on computer screen. Additional scans are integrated to the incomplete (white) areas.

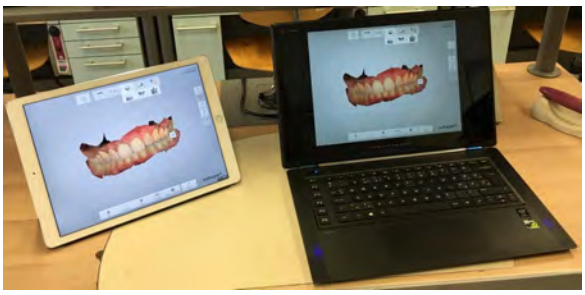

Figure 15. Scanned image can be displayed on computer screen and simultaneously on dental laboratory devices. It helps communication between lab and dental office.

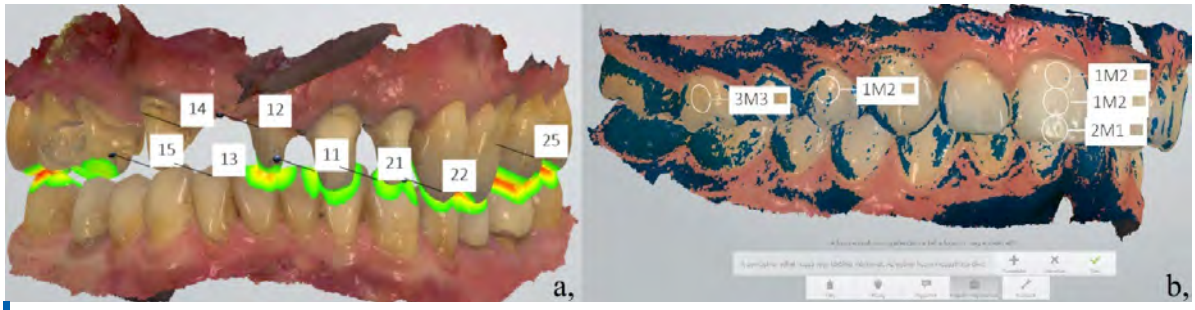

Figure 16. Built in software features of intraoral scanners (such as occlusal analysis) make dentists' work lot easier. Some scanners determine tooth shade and are equipped with intraoral cameras, thus expanding the possibilities of communication between dental lab and dentists.

to decrease in the future as the cost of production of scanners is declining.

4.2.2. Advantages of intraoral scanning

One great advantage is that the virtual model can be evaluated immediately chairside on the computer screen and the preparation can be modified if needed (Fig.14).

Built-in features of the software help to find not properly scanned surfaces and scan the approximal areas. The software provides data on adequate material thickness corresponding to the type of the dental appliance. The virtual model can be modified easy and quick, there is no need to rescan the whole arch.

Scanning is more time-efficient than conventional impression-taking. No time needed for mixing, setting, disinfection or casting.

In addition, digital impression taking is an environment-friendly procedure, as it eliminates the large amount of hazardous waste generated by conventional impressions in dental practices. Ease of documentation is an important advantage. Digital models never wipe, break, wear out. Patient documentation can be stored digitally on a hard disk or in the cloud and can be recalled at any time. (Fig. 15)

Intraoral scanners have additional functions such as color display and intraoral camera. These functions also help patient communication as they make the lesions visible. Some scanners are able to determine tooth shade and forward that information to the dental laboratory (Fig. 16).

The scanned data are also an excellent tool for treatment follow up and to evaluate the patients' dental status. At the University of Zurich, Zimmermann et al. created a digital database, which records the patient's

Figure 17. Digital impressions save the original form and shape of patient's teeth. The data can be stored for years and help planning of dental treatment later.

initial status and treatment scans. The final aim is the evaluation of long term changes in the dental status, such as dental migration, rotation, gingiva recession, abrasions etc. [7, 24] (Fig. 17).

Data of intraoral scanning can be fused with data of other 3 dimensional methods, such as CT and CBCT. This option opens up completely new perspectives for diagnosis, treatment plan, and planning of dental surgeries, already used in orthodontics and dental implantation. Modern undergraduate educational programs in implant dentistry (including digital prosthetic treatment) can provide proffessional care and a high treatment quality for the patients [25].

5. Conclusions

Digital dentistry is here to stay and it offers quick and comfortable experience to the patients and an efficient workflow to the dentist and dental technicians. The learning curve is steep to adopt that new technology both in the dental office and on the laboratory side.

To have the potential to keep pace with the digital era change there is a need for education at the undergraduate and postgraduate university levels and also at the level of the dental designer training programms.

Author contributions

All the authors (JB, AC, VV, IR, PH) declare to be accountable for the whole content of the article.

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Doctor Borbély is an Associate Professor at the Department of Prosthodontics, Semmelweis University, Budapest, Hungary. She graduated from the Dental Faculty of Semmelweis University of Medicine, Budapest, Hungary in 2001, then she began to specialize in prosthodontics. She received her PhD degree in 2008 on visual and digital methods for tooth shade selection. She also works in private practice focusing on prosthodontics and aesthetic dentistry. Since 2011 she has been working with digital impressioning systems. She conducts ongoing clinical research in digital prosthodontics and materials research. She presents lectures, hands-on clinical and postgraduate courses on ceramics, tooth shade selection and intraoral scanning. She is a presidential member of the Hungarian Prosthodontic Association and Hungarian Dental Association, she is a member of Society for Color and Appearance in Dentistry and Hungarian Academy of Esthetic Dentistry.

Questions

1. Intraoral scanners cannot be based on:

❑a. Confocal laser technology;
❑b. Confocal microscopy;
❑c. Triangulation;
❑d. Scanning probe microscopy.

2. It is not true for open CAD/CAM systems:

❑a. Files can be opened by the manufacturer's CAD software only;
❑b. For example 3Shape Trios and Planmeca Planscan;
❑c. It is compatible with several types of CAD softwares;
❑d. It is compatible with several types of milling machines.

3. What does accuracy consist of?

❑a. Trueness and deviation;
❑b. Precision and deviation;
❑c. Trueness and precision;
❑d. Quality and quantity.

4. Which material cannot be milled by dental CNC machines?

❑a. PMMA;
❑b. Ceramic;
❑c. Titanium;
❑d. Gold.