REVIEW

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THE MODERN DIGITAL INTRAORAL SCANNING SYSTEMS: A REVIEW

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Abstract. *The last decades were characterized by rapid progress in the introduction of new digital technologies in the field of prosthetics. The intraoral scanning systems are data acquisition devices which make it possible to make precise prosthetic structures, to identify carious lesions, orthodontic anomalies. This article analyzes modern trends in the field of newly developed intraoral scanning technologies published in scientific journals in recent years. It summarizes the information provided by various databases: PubMed, ResearchGate, Google Scholar and on the internet sites of manufacturing companies. As a result, a historical review was made with a focus on the development of intraoral scanning systems and their characteristics, advantages and disadvantages were thoroughly discussed.*

Key words: *Intraoral scanning systems, CAD/CAM technologies, analysis*

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INTRODUCTION

Nowadays, mathematics has a significant impact on the development of human activities. It should be borne in mind that the degree of its development depends on various factors and its role has developed historically. These factors include the development of mathematical concepts and mathematical apparatus, as well as the degree of development of digital technologies. The introduction of new digital technologies in the field of dentistry has led to numerous improvements that have their advantages for both the dentist and the patient. Modern digital technologies offer a fully computerized workflow that does not include the standard phases associated with impression taking [1]. The digitalization trend in dentistry has led to the advancement of computer-aided design and computer-aided manufacturing (CAD/CAM) technologies, which are widely used in the field of prosthetics. New data acquisition devices, such as intraoral scanners, provide multiple advantages in daily clinical use [2]. The intraoral scanner is a tool with many diverse applications in practice. It makes it possible to make precise prosthetic structures, to identify carious lesions, orthodontic anomalies. This makes it applicable and convenient to use in various fields of dentistry [3]. Intraoral scanners are devices used to directly create digital impression data of the oral cavity. Like other 3D scanners, they project a light source onto the object whose image is to be digitized. Specialized software creates a 3D model of the scanned surfaces with accurate details of the relevant anatomical structures [4, 5, 6].

The scanning system consists of three main components: a handle with a camera to collect the data

from the scanned objects in the patient's mouth, a computer monitor to visualize the digital files and software to store the information. The smaller the scanning handle, the more flexible it is and can provide more accurate and precise data [3, 5]. In some digital impression taking systems, the tooth surfaces are covered with a specially designed powder, in order to scan the two dental arches and the bite, while others allow a three-dimensional image to be created without powder coating [6, 7].

The principle of operation of intraoral scanners (IOS) is as follows:

Laser or white light energy is emitted from the handle. The object to be scanned reflects this light back to the sensor or camera. Based on programmed algorithms, measurements are made per inch, resulting in a 3D representation of the shape of the object. The technology used by the data acquisition handle determines the measurement speed, resolution and accuracy of the scanner. Four types of imaging technologies are currently in use [3, 6]:

1. Triangulation – measures angles and distances from known points with projected laser light. The distance between the laser source and the sensor is known, as is the angle between the laser and the sensor. As the light is reflected from the object, the system determines the angle of reflection, and therefore the distance from the laser source to the surface of the object. To ensure uniform and predictable light scattering, this technology requires the application of a thin layer of opaque powder on the fabric [3, 6].
2. Parallel confocal imaging directs laser light through a filter hole at the target tissue. The sensor is placed in the focal imaging plane relative to the target tissue, and a small baffle in front of the sensor blocks any light above or below the focal plane. Only the focused light reflected from the target tissue re-enters the filter and reaches the sensor for processing. Unfocused light is eliminated, thereby maximizing scanning accuracy [3, 6].
3. Interferometry uses two light sources that project three "spots of light" onto the teeth and tissues. When the "spot of light" hits the surface, it "distorts" and takes on a new color. This distortion is called "line curvature". Curvature data points are recorded by a high-definition video camera and visualized on a screen [3, 6].
4. 3D video uses an HD video camera with trinocular imaging – three tiny video cameras in the lens – to capture three views of the tooth. An additional semiconductor sensor behind the cameras converts light energy into electrical signals. Distances between points are calculated to determine the 3D data, which is recorded in a video sequence and visualized in real time. A powder coating is required to capture the points. The purpose of powder coating is to improve scanning accuracy by increasing the number of surface data points and ensuring uniform light scattering [3,6].

Capturing a digital teeth impression takes approximately one minute. The operator has the ability to review the electronic image in real time, can magnify and manipulate it to ensure that any possible errors are identified and corrected on the screen before the digital tooth print is sent to the dental laboratory [7].

AIM OF THE STUDY

The aim of the presented literature review is to examine and critically analyze the modern intraoral scanning systems.

For this purpose, a search was conducted in various databases: PubMed, ResearchGate, Google Scholar and internet sites using keywords – "intraoral scanners, laboratory scanners, digital impressions, CAD/CAM". The survey was conducted in the period November-December 2022, 1338 scientific sources have been found. Detailed analysis showed that 40 of them met our target. The collected scientific information was systematized according to 3 main criteria: historical overview in the development of IOS, advantages and disadvantages of scanning systems, characteristics of IOS.

HISTORICAL OVERVIEW IN THE DEVELOPMENT OF INTRAORAL SCANNERS

In modern prosthetic dentistry, there are basically two approaches when creating prosthetic restorations – conventional and digital [8]. Conventional impression taking methods are widely established in prosthetic dentistry. With the development of materials and the introduction of newer and more advanced ones, the qualities of impressions are optimized. However, it is known that in most cases there is shrinkage of the impression material, which is compensated by the expansion of the plaster when casting working models. The resulting impressions, however, do not accurately reproduce the features of the prosthetic field. This is due to the imperfections of the impression materials used in the past. Later, the materials acquired better qualities, which defined them as very widely applicable in practice today, but the process of taking an impression in most cases is unpleasant for the pa-

tient and takes clinical time. For this reason, impression taking is usually separated into a clinical stage [9]. Impressions showed least distortion at varying degrees of temperature for 20 minutes, but the values obtained by storing of alginate impressions for 20 minutes at 30ºC were found to be nearly accurate than the values obtained by storing of impression at 40ºC. However, storing showed shrinkage of impressions [10]. To overcome these limitations, intraoral digital scanners have been developed as an alternative to traditional impressions [11].

The introduction of digital systems coincided with the development of CAD/CAM technologies. In the 1970s, the concept of computer-aided design/computer-aided manufacturing (CAD/CAM) was first introduced into dental practice by Dr. François Duret. In 1985, the first intraoral scanner became commercially available. According to [6] with the introduction of the first digital scanner, a good alternative to conventional prints was offered. Modern versions of intraoral scanning systems differ significantly from the original ones, as their characteristics are significantly improved. However, digital technologies have continued to evolve over the last decades. Scanners are being created that are even faster, more accurate and smaller in size. These advantages determine greater convenience in the work process and ease of use of IOS [5, 6, 12, 13].

ADVANTAGES AND DISADVANTAGES OF THE INTRAORAL SCANNING SYSTEMS

As a result of a number of studies, it has been found that taking a teeth print using a scanning device has many more benefits compared to the conventional technique. Digitization of the work process in prosthetic dentistry, in addition to its advantages, also has some disadvantages. Significant advantages are:

Advantages

Time efficiency

Many researchers found that taking an impression for a prosthetic structure using a scanning device was much faster than conventional methods. This saves time and money, and the procedure is also easier to perform [8, 14, 15].

Patzelt et al. [16] used three different intraoral scanners to digitize a single abutment (scenario 1), a short-span fixed dental prosthesis (scenario 2) and a full-arch prosthesis preparation (scenario 3). The mean total procedure durations for making digital impressions of scenarios 1, 2 and 3 were as much as 5 minutes 57 seconds, 6 minutes 57 seconds, and 20 minutes 55 seconds, respectively. The compiled procedure durations for making conventional impressions in scenarios 1 and 2 ranged between 18 minutes 15 seconds and 27 minutes 25 seconds; for scenario 3, they ranged between 21 minutes 25 seconds and 30 minutes 25 seconds [16]. Sometimes shorter scanning times are associated with poorer coverage quality, with the operator needing to make corrections by adding extra images [17].

Reduced discomfort for the patient during the impression taking procedure

One of the greatest advantages, cited in a large number of scientific articles, of modern intraoral scanners is the reduced discomfort for the patient during the impression-taking procedure. This is particularly important, as it overcomes the fear of patients, and in those with great sensitivity, the nausea reflex is significantly reduced. This is a significant benefit, as it is sometimes very difficult to take an accurate impression, and this affects the quality of the final construction [1, 8, 14, 15]. Impressions obtained by digital methods have high accuracy, as some of the disadvantages of impression materials have been successfully resolved – deformation, temperature sensitivity, sensitivity to moisture, limited operating time, presence of bubbles in poorly conducted work process, tearing of the impression [3, 8, 15, 18, 19]. According to Cicciù et al, communication between the dentist and the patient is significantly improved. Digital imaging makes it possible to digitize the treatment plan as well. All this happens immediately, in real time [1]. With this, a better awareness of the patient is achieved, and in addition, his motivation for the upcoming treatment is increased [18].

The resulting digital teeth print can be stored electronically for an unlimited period of time. This is an important advantage, which makes it possible to follow the change in the condition during and after the end of the treatment [7].

Another great advantage of this technology is that it results in saving the casting of a working plaster model by the dental technician [8, 15, 20, 21]. Improper casting of a working model causes imperfections in the fabrication of the prosthetic structure. The latter leads to improved communication between the dentist and the dental technician. With the use of IOS, the clinician communicates in real time with the laboratory, and in case the dental technician is not satisfied with the quality of the impression, it is possible to repeat the scan immediately [13].

Digital scanning was more time-efficient and was preferred by patients for all 4 analyzed outcomes (comfort, anxiety, nausea, time perception) [22].

Accuracy

The quality of the scan is of utmost importance, as it determines the accuracy of fabrication of the prosthetic structure. Different types of scanning systems are available today, but they must be carefully researched and selected based on certain criteria. One of the most important criteria that must be taken into account when choosing an intraoral scanner are accuracy, speed, software. Based on a number of studies, differences in these indicators have been found for different types of scanners.

The accuracy of the scanning devices was determined through extra- and intra-oral studies. Extraoral scans of cast models show greater accuracy than intraoral scans. This is because there are factors operating in the oral cavity that can make scanning difficult – for example, anatomical features of the teeth, prominence of the alveolar ridges and palatal arch, presence of saliva, mucosal topography, limited space [23]. Accuracy is defined by precision and reliability. Precision shows how close repeated measurements are to each other, i.e. what is the similarity between them, and reliability – how far the obtained image deviates from the actual parameters of the scanned object. Accuracy thus describes the correspondence between the actual scanned anatomical structure and its reproduction in the virtual model [6, 23, 24, 25, 26, 27, 28]. Scan accuracy may be affected by made operational decisions such as the selected scanning technology and IOS system, device calibration, scanning method, scanning conditions [29]. Accuracy is significantly affected by the reflectance, refractive index, and transparency of the object. Models made from highly reflective materials such as alloys have optical properties that are challenging to scan. Materials that have less transparency or are less reflective create a better scanning environment [21, 27].

Making an accurate implant impression is a crucial step in constructing implant-supported prostheses. During implant impressions making, the concentration is to accurately reproduce the implant location in 3 dimensions in relation to the other structures in the mouth. In vivo pilot studies showed that digital scanning is not reliable and could not be used in clinical routine [30]. Another investigation received opposite result – fully digital implant-prosthetic protocol provided a smooth, complication free and time effective treatment alternative to the conventional workflow [31]. The accuracy (trueness and precision) of complete-arch digital implant scans using intraoral scan bodies was affected by both the scan body and scan technique when using an intraoral scanning system. The Zimmer biomet dental scan body had significantly less distance deviation, whereas splinting scan bodies with floss led to significantly more distance deviation. The scan techniques with different surface modifications were not found to improve the scan accuracy. The use of different intraoral scan bodies led to significant differences in the scan time [32].

Disadvantages

Despite the many advantages, IOS have some disadvantages. They are related to the experience of the dentist, performing the scan, the scanning strategy, distance from the scanned object, the type of scanning device, anatomical features (shape of the prepared tooth stump, shape of the palatal arch and alveolar ridge), the conditions in which the scan is performed. The operator experience is also very important [4]. It is much easier for young specialists to replace traditional teeth printing techniques than for more experienced ones who have certain difficulties in operating with new technologies [4].

Scientists find that scanning is closely related to the software for connecting the scanned images. If the scanner movement is too fast or there are sudden changes in orientation, the data fusion process can be compromised. For this reason, it is important that the dentist is well trained and that the scan goes smoothly [8, 21].

Other disadvantage of this technology is the possibility of compromising the impression, which is due to deteriorated conditions in the oral cavity – temperature, presence of liquid medium (saliva, blood) as well as the high initial investment for the purchase of IOS and its software [33, 34].

FEATURES OF INTRAORAL SCANNERS

The development of IOS affects their shape and size. Modern systems have a small, compact handle that scans even the most difficult-to-reach areas of the dentition, without any discomfort for the patient. When choosing an intraoral scanner, speed and scan flow are important factors. 3D digital models can be generated in minutes, significantly reducing the overall work time. As the IOS develop and improve, so does the scanning speed. Today, the scan of the entire dental arch is performed in about 1 minute, again influencing the experience of the dentist [5]. Scan flow is related to how smoothly the process runs – does the scanner lose its position, does it move smoothly from one scanning area to another, if for some reason the process is interrupted, will the device then pick up where it left off, how quickly images assembly is in progress [35].

In order to visualize and store the image of the scanned object, specialized software is required. An image is saved as a Standard Tessellation Language (STL) file. The file can then be used to produce a wide variety of prosthetic designs [21, 36]. Some scanners only scan and export files. Others provide a huge range of software, such as simulation, smile design, 3D printing model creation. There are a number of types of intraoral scanners available on the market today. In this literature review, some of them will be presented – 3Shape – TRIOS 4, Dentsply Sirona – Cerec Primescan, Medit i700, iTero, Launca. Their characteristics are described by the Institute of Digital Dentistry (IDD) [35].

3Shape – TRIOS 4

TRIOS 4 is the fourth generation TRIOS scanner, which is an improved version of TRIOS 3. TRIOS is a powder-free system that scans in color, allowing the dentist to more easily identify the boundaries of the scanned structures. The TRIOS system automatically reads the shades of adjacent teeth during the scan and provides this information along with the digital impression [37]. TRIOS 4 is fast, powerful and easy to use. It comes in multiple configurations, such as POD (USB) or TRIOS MOVE (Cart scanner). Through it, a scan of the entire dental arch can be achieved within 45 seconds, which shows its high speed. TRIOS 4 is also available with a surface caries detection function. Another advantage of TRIOS scanners is the range of "patient engagement" applications they include, such as patient monitoring, smile design and orthodontic simulation. TRIOS 4 has a new platform based on applications and is one of the few wireless scanners on the market. The 3Shape system also has an even newer scanner – TRIOS 5, where the features are even more improved [38].

Dentsply Sirona – Cerec Primescan

Primescan is also an extremely fast and high-tech scanner. It has artificial intelligence that makes the scanning process very efficient and provides one of the smoothest scans. It has one of the largest "fields of view" – it captures a lot of data even when it is held in one place. In terms of software, it is available in two variants – with CAD design software included (CEREC Primescan AC with CEREC software) or just for sending the image to the laboratory (Primescan AC with Connect software). The scanner has limited software applications, such as a smile design application. Other applications found in competing models, such as caries detection, orthodontic simulation, are not found in CEREC software. The CEREC system has some limitations – the inability to export print models and the inability to import scans from other iOS devices [39].

Medit i700

Improving on many aspects of the previous generation Medit i500, the i700 scanner is extremely fast. It provides scanning similar to that of some of the best scanners on the market.

The Medit i700 is a USB scanner and can be used with any computer but requires an online connection to work. Unlike the previously mentioned scanners that have CAD software, this scanner does not. However, it has some good software applications – smile design, orthodontic simulator, model building and temporary structures [40].

iTero

The iTero intraoral scanner uses parallel confocal imaging to capture a color 3D digital impression of tooth surfaces, contours and surrounding gingival tissues. The scanner has the ability to capture teeth for crowns, bridges, inlays/onlays, veneers. The iTero system is used only for digital impressions and does not have a dedicated milling machine, although its open platform can be integrated with design software [37]. A major disadvantage of this scanning system is the low efficiency when scanning the entire dental arch. Also, the scanner is disturbed when passing through soft tissues, which slows down the formation of the image [15, 41].

Launca

Launca is available in two forms – USB scanner and Card scanner. Both devices are scanners only, with no CAD software or software applications. It has low penetration and therefore needs to be held in a certain position over scanning surfaces to capture an image (much closer than other IOS). The scanner is relatively fast. The disadvantage is that it has a complex scanning methodology, which complicates the process and extends the operating time. In addition, it is difficult to maintain a continuous scan of the entire dental arch. This is partly due to the specific focal length and the fact that the scanner does not recover very quickly if it loses its place. The device has a relatively small "scanning window" as the software is for scanning only. It can capture images as well as make only basic edits, such as deleting option. It does not have software applications [42].

The listed characteristics of intraoral scanners draw attention to the imposed trend of updating and optimizing their clinical application. All of them are subject to changes that aim to improve and facilitate their use. The changes are mainly aimed at reducing their size, increasing the speed and accuracy of scanning.

The advancement of these devices means adding more features through various applications. Table 1 presents main advantages of the considered 5 technologies according to selected criteria – speed and accuracy of scanning, configuration, software, additional applications.

CONCLUSION

Developing digital technologies are leading to a progress in various fields of science [43-51]. Dental medicine, as a modern science and a significant section of general medicine, also features a natural transition from widely applicable conventional methods to new modern digital technologies visualizing the work process. This necessitates the clinical use of intraoral scanning systems to become more and more widespread. Based on the results obtained from the conducted literature survey, we can conclude that each IOS has advantages as well as disadvantages. The considered characteristics of IOS can be summarized in favor of advantages. They offer easier treatment planning, a shorter workflow and more accurate results. With their specific characteristics, the scanners can be used in various areas of dentistry.

One of the most significant features of the IOS workflow is reduced patient discomfort. Taking an accurate impression is of great importance for the quality of the prosthetic construction. For this reason, it is important that the patient feels comfortable while the impression taking process takes place. One of the important advantages of digital scanning systems is undoubtedly their accuracy. It is determined by the continuous refinement and improvement of the characteristics of new generations of intraoral scanners. On this basis, they are increasingly applied in daily dental practice. At the current stage of work, digital technologies have their place, but they undoubtedly need even greater popularization in our country.

Table 1. Features of 3Shape-TRIOS4, Dentsply Sirona – Cerec Primescan, Medit i700, iTero, Launca

	3Shape – TRIOS 4	Dentsply Sirona – Cerec Primescan	Medit i700	iTero	Launca
Scanning speed and accuracy	Very high	Very high	Very high	Relatively high	Low
Configuration	USB scanner and Cart scanner	Cart scanner	USB scanner	USB scanner and Cart scanner	USB scanner and Cart scanner
Software	It has its own software and CAD/CAM Software	It has its own software and CAD/CAM Software	It does not have its own software and CAD/CAM Software. The data is stored in the cloud	It does not have its own software and CAD/CAM Software	It does not have its own software and CAD/CAM Software
Additional applications	Ability to identify caries, smile design, orthodontic simulation and patient observation	It does not have additional applications	Smile design and orthodontic simulation	Capable of caries identification, orthodontic simulation and patient observation	It does not have additional applications

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