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Direct digitalization devices in today's dental practice: Lab scanners an update and review

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Abstract
Every day, modern dentistry faces with new technologies, which have begun to be used in daily clinical practice, and computer-aided design and computer-aided manufacturing has brought new technologies and opportunities to all fields of dentistry. The first step is acquiring the true data, which belongs to the patients, digitalization of intraoral structures. By acquiring these data, the restorations can be designed and fabricated by using digital workflow. Dentists have two main options for capturing the data from the related surfaces; one is the direct digitalization and the other one is the indirect digitalization process. In the indirect process, extraoral scanners, which are called lab scanners or cast scanners, are used. Every system has different advantages and disadvantages, and the clinicians or dental technicians should know the technology and different features of these devices to choose the optimal device for their workflow.

Keywords: digital, digital dentistry, digital workflow, extraoral scanners

1. Introduction

Computer-aided design and computer-aided manufacturing has brought new technologies and opportunities to all fields of dentistry, which includes digitalization of intraoral structures, and design and manufacturing stages (Strub et al., 2006; De Villaumbrosia et al., 2016). This technology started with Dr. Werner Mörmann at the 1980's, and it has been developed every day since its introduction (De Villaumbrosia et al., 2016). The digital workflow can be described as a workflow, in which each phase of the treatment procedure is conducted by digital devices. By this workflow, more precise, more predictable, and more accurate results can be obtained. Moreover, the use of prefabricated materials provides a standardization in manufacturing, and most of the fabrication errors can be eliminated (Prasad and Abdullah Al-Kheraif, 2013).

This digital process includes three main steps; data acquisition (digitalization of intraoral anatomy) (Fig. 1), design process, and finally manufacturing. The first and the most important step of this workflow may be the digitalization of intraoral anatomy because if a clinician cannot obtain the true data, the final result will not be precise (Chan et al., 2011).

Currently, clinicians have two main choices for the digitalization of anatomical structures: (1) direct digitalization with intraoral scanners, (2) and indirect digitalization with cast scanners. Intraoral scanners have many advantages, such as direct digitalization from patients mouth and no need of plaster cast, and chairside workflow completed in the clinics. Nevertheless, dental laboratories may obtain the data by using lab or cast scanners. Both type of scanners obtains a digital model of patients mouth by acquiring images, and subsequently processes a triangulation by the help of CAD software (Miyazaki et al., 2009; Chan et al., 2011). At the end of the process, the obtained files are used to fabricate restorations via different manufacturing alternatives, such as three-dimensional (3D) scanners or milling machines by using polymethyl methacrylate, resins, alloys or different ceramic materials (Ebert et al., 2009; Kachalia and Geissberger, 2010; Fielding et al., 2012; De Villaumbrosia et al., 2016).

Cast scanners can be classified as follows: contact and non-contact scanners. In terms of used technology, cast or extraoral scanners mainly use three different technologies. These are visible structured light, laser or contact type scanning (Lee et al., 2017). In contact scanners, a digital cast is created by directly touching to the cast with a probe, and computing the x, y, z coordinates for each location, which are read by the probe. Even if this approach is highly accurate, it has also some drawbacks: (1) it takes a long period of time, (2) and it is possible to damage to cast model during the scanning (May et al., 1998; Persson et al., 2006; Lee et al., 2017).

The laser scanners and optical scanners are classified under the non-contact category. Although the laser scanners are precise, they are not as fast as the optical scanners. Additionally, the laser scanners have a different drawback, which is called "speckle" (Persson et al., 2006; Jeon et al.,

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2013; Lee et al., 2017). The optical scanners capture images by using both white and blue light. The main difference between white and blue light is ambient light amount, and this may cause a misfit when it is too much (Jeon et al., 2015). Intraoral scanners can be affected by several complex environmental factors, such as humidity, saliva, movement of the patient. Even if there are more or less factors, which affects the accuracy of digital impressions when compared with conventional ones, the technology directly affects the accuracy (Jeon et al., 2015; Lee et al., 2017).

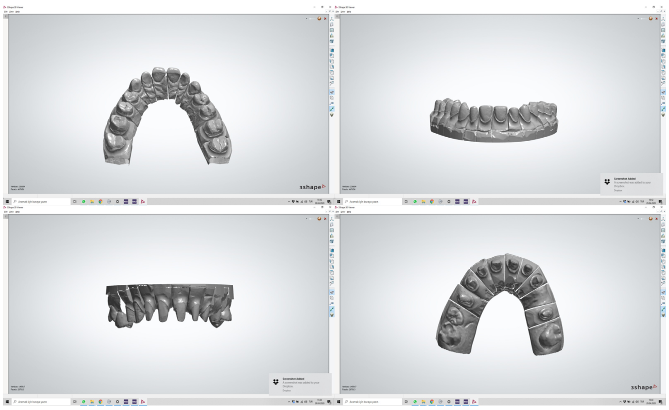

Fig. 1. An example of scanned plaster cast from different views, which are captured by an extraoral scanner

2. What is the technology of the cast scanners?

Approximately all 3D scanners work on the same principle. They have one light source, one or more cameras, and a motion system that supports several axes to position the scanned objects towards the light source and cameras. Structured light generates well-designed lines on the surface of the model, and cameras subsequently can detect the images of these lines. Based on the known angle and distance between the cameras and light source, 3D positions can be calculated where the structured light, which reflects from the surface of scanned object. This is based on trigonometric calculations and named as triangulation.

In most of scanner systems, only one camera works; however, two cameras increase the scanning speed and accuracy. Each projected line causes a 3D contour line. Laser scanners generate multiple lines by moving the scanning head along a precise axis. In contrary, white light scanners do not have a movable scanning head. By moving the object, several projections can be detected from different angles. Although these two different types of scanners have different technologies, it is difficult to say which one is better.

Some 3D scanners support a high-quality mechanical motion system, in where all 3D views can be directly transformed into a common coordinate system and then simply appended to each other. Other 3D scanners with less accurate mechanics do not rely on the quality of motion system, instead, they virtually align the 3D views by detecting similar 3D structures in overlapping regions of at least one pair of views. Software alignment thus works best for objects with pronounced structures, e.g., molars (Shembesh et al., 2017).

Triangulation process needs some sharply projected light patterns. This can be obtained by both laser and white or structured light scanners. Laser scanners can achieve minimal light projections of the scanned surface; however, if they are not controlled carefully, this may cause speckle that can be defined as slight randomness in light intensity. However, white light scanners may cause blur effect due to different color components of white light (Shembesh et al., 2017). As a result, the accuracy of devices is directly related to the resolution of the cameras, which cast scanners have. Today, most of the developing scanners have five megapixels or above cameras (Table 1).

In the final step, the point cloud, which is obtained from every aspect of objects, is converted into a 3D surface of fine triangles. This step can be achieved by software algorithms and smart surface generation algorithms. By using smart algorithms, the number of triangles can be significantly reduced without any problem in accuracy. So, why reducing the triangles number is necessary? The answer is about the CAD design software. Processing the 3D image takes much more time unless the triangles are reduced (Shembesh et al., 2017).

3. Which type of cast scanner?

A 3D scanner is a technological device capable of capturing and processing images or video files from the surface of a restoration cite for fabricating a digital copy. Cast scanners are either tactile or optical. Tactile scanners are known as contact scanners, and these kinds of scanners acquire the data and capture the surface details by contacting via the help of detection unit.

Optical scanners, also known as noncontact scanners, capture the images using laser or structured light. Contact scanners are more precise, but they work slowly during digitization process. This type of scanners are the first introduced scanners on the market, and they are the most accurate ones. Nevertheless, they are slow because they need to contact every point of the entire scanned surface by a moving probe. Nowadays, they are rarely used in the laboratories. Contact scanners employ a probe made of a very resistant material, such as ruby. These types of scanners are not affected from the optical characteristic of surfaces, but they can be affected from the surface characteristics of materials.

Non-contact scanners use structured light or laser for detecting the surface properties and capture the scanned surface digitally. This type of scanners is extremely fast when compared with contact type of scanner, and they do not create distortions on the scanned surface. However, light can be affected from the surface properties, and may show reflective behavior, and this can change the light reflection characteristics, which is directly related with accuracy. Non-contact type scanners capture the entire surfaces to collect much more data at the same time; and therefore, they can be more precise (Tamimi and Hirayama, 2019).

Table 1. Currently available extraoral scanners with information of their technology, manufacturer and accuracy

Technology	Scanner	Manufacturer	Accuracy
Structure Light	AutoScan-DS300	Shining (Hangzhou, China)	10 µm
	Cara Scan	Kulzer (Hanau, Germany)	15 µm
	Cendres+Metaux	Cendres Metaux (Biel, Switzerland)	5 µm
	Ceramill Map 400	Amann Girbach (Koblach/Austria)	6 µm
	D2000	3shape (Copenaghen, Denmark)	8 µm
	Dental Scanner MDS 550	Maestro (Pisa, Italy)	10 µm
	Deluxe 3D Optical Scanner	Open technologies (Rezzato, Italy)	5 µm
	inEos X5	Dentsply/Sirona (Bensheim, Germany)	7 µm
	Identica T500	Media (Incheon, South Korea)	2.1 µm
	IScan L1	Imetric (Courgenay, Switzerland)	7 µm
	Kavo LS3 Scanner	Kavo (Biberach, Germany)	<15 µm, depending on the type of case
	S900 Arti	Zirkonzahn (Gais, Italy)	10 µm
	Vinyl	Smart Optics (Bochum, Germany)	6 µm
	Evolution Plus	Zfx (Munich, Germany)	9 µm
Laser	7 series	Dental Wings (Montreal, Canada)	15 µm
	ConoScan 4000	Optimet (Jerusalem, Israel)	10 µm
	Cyno Prod i3.5	Numeq Inc (Quebec, Canada)	30 µm
	OpenScan 100	LaserDenta (Berghain, Germany)	20 µm
	Orapix 3D scanner	Orapix (Seoul, South Korea)	20 µm
	ShapeGrabber	ShapeGrabber (Ottawa, Canada)	40 µm
	Zeno Scan S100	Wieland (Pforzheim, Germany)	50 µm
Contact	Procera Forte	Renishaw (Gloucestershire, UK)	1–2 µm
	Renishaw Incise	Renishaw (Gloucestershire, UK)	1–2 µm

4. Accuracy

Of course, every step of dental fabrication process has potential source of errors. So, every step is very important for avoiding inaccuracies, and accuracy is an important criterion for restorative dentistry. In the conventional workflow, accuracy can be affected by a lot of factors, such as humidity, isolation of the impression area, type of impression material, dimensional stability of the impression materials, dimensional stability of the cast material, and etc. Digital technology eliminates most of these factors, but the key question is: are the digital impressions comparable with conventions impressions? Unfortunately, there is no common standard for measuring or validating the accuracy of dental scanners as in vivo. Almost all researches are performed in vitro and also comparing the results is not very easy due to lack of standardization of the methodologies (Tomita et al., 2007).

Another important question is that may we have to ask is can the difference in technology of cast scanners affect the accuracy of digital impressions De Villaumbrosia et al. (2016) reported that the mean accuracy values, which were obtained by six different extraoral scanners, were higher than those of declared by manufacturers. There is no doubt that the accuracy is affected by how well the scanner is manufactured. In mechanical movement systems with have high accuracy, the different captured images are stitched. Nevertheless, software alignment in less accurate systems mainly depends on the matching of the surface structures in overlapping areas. This is potentially prone to inaccuracies especially in small, smooth, and less defined areas. De Villaumbrosia et al. (2016) also found that each scanner had a less discrepancy on the axial surface than margin and occlusal groove areas. In other words, the researches revealed that extraoral scanners are much more accurate on smooth surfaces than sharp angled areas (Rudolph et al., 2007; De Villaumbrosia et al., 2016).

When the related literature evaluated, the accuracy and trueness values of cast scanners are less than intraoral scanners. Vlaar and Van Der Zell (2006) reported a discrepancy between 7.7 to 13.9 µm. Persson et al. (2006) showed that the trueness of a contact scanner was within 10 µm. Delong et al. (2003) found that the average values changed between 18 to 30 µm for a cast scanner, which used structured light (De Villaumbrosia et al., 2016). Another factor is the resolution for evaluating and determining the trueness of different cast scanners. De Villaumbrosia et al. (2016) reported that the correlation between the resolution and other variables are irregular. The higher resolution may provide much less misfit in sharp edges and complex surfaces, and this statement also was reported in different studies (Arnetzl and Pongratz, 2005; Al-Fadda et al., 2007; Quaas et al., 2007; Del Corso et al., 2009). This may be because the scanner records some points which is called “point of interest” (POI) on the scanned surface. Noncontinuous reading at sharp and complex surfaces scanners tend to measure the edges. In the high-resolution scanners, this would be finer when compared with low-resolution scanners, because the scanner software fills the gaps among POI on the sharp edges. However, it would be beneficial to explain that the higher resolution mainly does not imply a higher accuracy (trueness and precision) but only the capability of recording in detail (Persson et al., 2008; De Villaumbrosia et al., 2016).

It was reported in a study that the contact scanner which had the highest resolution (216.4 points/mm^2) showed the lowest discrepancy values (Joós-Kovács et al., 2019). In contrary, the laser-based scanners had the best results regarding the precision and trueness. On the other hand, studies show that there is no correlation between the triangulation numbers and accuracy, and the quality of points that captured by the scanner and point cloud generated by the algorithm are more important (Joós-Kovács et al., 2019). As a consequence, technology may directly affect the accuracy of scanners.

5. Scan speed and productivity?

Scan speed is a very important factor on the overall success, especially in laboratory workflow. As for accuracy, it is difficult the say which scanner is faster due to standardization problems. Although, there is no common and standard reference, some comparisons showed that scanning times can be vary from 30s to several minutes for the same basic die. However, there is no doubt that the scanning time is not a meaningful factor on the overall productivity.

The more important point in productivity is the high degree automation of hardware because this will prevent or correct many human source errors. For example, the adjustment of manually controlled camera brightness can result in over-exposed images, in which projected lines of light can no longer be detected. Some hardware features can save working time by using die feeder or multi die plate. Good fixture reduces the number of failures, which is an annoying source of wasted time. As a result, even if the speed is very essential and important on the productivity, this is not a factor that can be evaluated alone to assess the productivity.

6. Conclusion

Today many laboratories use extra oral scanners and these devices take place of conventional workflow. Several 3D scanners are presented every day. Due to lack of common standards, the increased choices can be confusing. During evaluating and comparing the devices, commonly accuracy, scan and workflow time, different useful features of devices, and supported indications should be considered. Even if cast scanners are not necessary for routine clinical use, they are indispensable to increase the fabrication quality and effectiveness.

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