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Commercially Available Intraoral scanners: a Literature Review

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ABSTRACT: Since the eighteenth century, conventional impression techniques have been used to register the three-dimensional geometry of dental tissues. Nevertheless, inaccuracies of impression materials and expansion of dental stone seem error-prone, and thus the process requires the services of an excellent dental laboratory. To overcome these difficulties, impression with IOS (intraoral scanner) was developed for dental practice. The implementation of the IOS device in dental practices coincided with the development of CAD/CAM (computer-aided design and manufacturing) technology in dentistry, with numerous advantages for practitioners. Nowadays, IOS and CAD/CAM provide easier planning of treatment, case acceptance, and communication with laboratories, reduced operative time, storage requirements, and reduced treatment times.

Key Words- Intraoral, scanners, 3dimensional, CAD,CAM

I. INTRODUCTION

Intraoral scanners (IOS) are devices for capturing direct optical impressions in dentistry. Similar to other three-dimensional (3D) scanners, they project a light source (laser, or more recently, structured light) onto the object to be scanned, in this case the dental arches, including prepared teeth and implant scan bodies (i.e. cylinders screwed on the implants, used for transferring the 3D implant position) .The images of the dentogingival tissues (as well as the implant scan bodies) captured by imaging sensors are processed by the scanning software, which generates point clouds. These point clouds are then triangulated by the same software, creating a 3D surface model (mesh). The 3D surface models of the dentogingival tissues are the result of the optical impression and are the 'virtual' alternative to traditional plaster models[1-3].

To overcome difficulties associated with conventional techniques, impressions with IOS (intraoral scanner) and CAD/CAM (computer-aided design and manufacturing) technologies were developed for dental practice. The last decade has seen an increasing number of optical IOS devices, and these are based on different technologies; the choice of which may impact on clinical use[4]. To allow informed choice before purchasing or renewing an IOS, this article summarizes first the technologies currently used (light projection, distance object determination, and reconstruction).

PATIENT COMFORT

The ability to directly capture all dental arch information of the patient, and consequently their 3D models, without using conventional physical impressions, is one of the advantages of optical impressions. In fact, the conventional physical impressions can cause momentary discomfort for the patient due to the inconvenience and hardship stemming from the materials positioned on impression trays (whether generic or individualized). Some patients (e.g. patients with strong gag reflex, or children) appear not to tolerate the classic procedure. For such patients, replacing conventional impression materials with light is an advantage; optical impression is therefore appreciated. Optical impression decreases patient discomfort significantly when compared to traditional physical impression[5].

TIME EFFICIENCY

Several studies have shown that optical impressions are time-efficient, as they enable reduction of the working times (and therefore costs) when compared to conventional impressions. Despite the recent technological advancements in IOS, with the latest devices introduced in the market enabling the capture of a full-arch scan in less than 3 min, it does not appear that the major differences in time efficiency stem from the act of making an impression itself (a full-arch scan may take 3–5 min, similar to that required for conventional impressions), but rather from the time saved afterwards, during all subsequent steps[6].

SIMPLIFIED PROCEDURES FOR THE CLINICIAN

Another benefit conferred by the use ofoptical impression is clinical. In fact, when the learning curve has been completed, the use of IOS

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may confer further clinical advantages, simplifying impression-making in complex cases, for example in the presence of multiple implants or severe undercuts that may render the detection of a conventional impression difficult and insidious[7]. Moreover, if the clinician is not satisfied with some of the details of the recorded optical impression, they may delete them and recapture the impression without having to repeat the entire procedure; this aspect is time-saving

NO PLASTER CASTS

For the clinician, optical impression allows the skipping of an otherwise unavoidable step (the conventional impression is based on the detection of physical impressions and subsequent casting of gypsum models) with a time-saving effect. The elimination of conventional impression materials translates into direct savings for the clinician, with reduced consumables costs[8].

BETTER COMMUNICATION WITH THE DENTAL TECHNICIAN

With IOS, the clinician and the dental technician can assess the quality of the impression in real-time.[9]In fact, immediately after the scan has been performed, the dentist can e-mail it to the laboratory, and the technician can check it accurately.

COMMUNICATION TOOL

Optical impression is a powerful tool for patient communication and marketing. In fact, with optical impressions, patients feel more involved in their treatment and it is possible to establish more effective communication with them; this emotional involvement may have a positive impact on the overall treatment.[10]

LEARNING CURVE

There is a learning curve for adopting IOS in the dental clinic, and this aspect must be considered with attention. Subjects with a greater affinity for the world of technology and computers (e.g. young dentists) will find it very easy to adopt IOS in their practice.

DETECTING DEEP MARGINS

One of the most frequent problems encountered with IOS and with optical impressions is difficulty in detecting deep marginal lines on prepared teeth or in the case of bleeding. In some cases, in fact, and especially in aesthetic areas where it is important for the clinician to place the prosthetic margins subgingivally, it may be more difficult for the light to correctly detect the entire finishing line.[11]

Not all scanners have the same set of functions, and we wanted to show this explicitly in our review. Therefore, we've divided them into three different classifications based on system capabilities. However, the intraoral scanners are rated purely on their own merits, and their **classifications are not taken into account**. The classifications are as follows:

Classification of intraoral scanners:

Class **A** = the manufacturer offers its own scanner, CAD software, and CAM (milling) unit.
Class **B** = the manufacturer offers its own scanner and CAD software only.
Class **C** = the manufacturer offers its own scanner only.

Digital scanners are used to replace traditional impressions, so we developed a three-tiered system based on traditional timings for easy reference.

- **Tier 3:** The scanner is able to complete a full-arch scan and export an STL model successfully, without time limit.
- **Tier 2:** The scanner is able to complete Tier-3 tasks faster than silicone impressions (around 5 minutes).
- **Tier 1:** The scanner is able to complete Tier-3 tasks faster than alginate impressions (around 1 minute).

SCANNING EFFICIENCY AND ACCURACY

Completing an intraoral scan is not simply a matter of whipping the scanner around as fast as you can. The scanner needs to also consistently acquire useful data for 3D model reconstruction. In the event that the scanner has captured bad data (i.e. tongue, cheeks, fingers, etc…) it needs to be able to fix them, preferably on the fly and without user intervention.

ACCURACY

The main feature an IOS should have is accuracy: a scanner should be able to detect an accurate impression. In metrics and engineering, accuracy is defined as the 'closeness of agreement between a measured quantity value and a true quantity value of a measurand' ultimately; Accuracy is the sum of Trueness and Precision [16].

Trueness:

Trueness, usually expressed in terms of bias, is the 'closeness of agreement between the expectation of a test result or a measurement result and a true value'. Ideally, an IOS should have high

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trueness (it should be able to match reality as closely as possible). An IOS should therefore be as true as possible, that is, be able to detect any impression detail and permit the establishment of a virtual 3D model as similar as possible to the actual model, and that little or nothing deviates from reality.[12]

The only means of calculating the trueness of an IOS is to overlap its scans with a reference scan obtained with a powerful industrial machine (industrial optical scanner, articulated arm, coordinate measuring machine) [4–8]. After the overlapping of these images/models, powerful reverse-engineering software can be used to generate colorimetric maps displaying the distances/differences between the surfaces of the IOS and the reference model at micrometric level

Precision

Precision is defined as the 'closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same objects under specified conditions'. Precision can be calculated more easily, simply by overlapping different scans/models taken with the same IOS at different times and again evaluating the distances/differences at micrometric level.[13,16]
Trueness and precision mainly depend on the scanner acquisition/processing software, which performs the most difficult task: 'building' the 3D virtual models
To date, the scientific literature considers the accuracy of optical impressions clinically satisfactory and similar to that of conventional impressions in the case of single-tooth restoration and fixed partial prostheses of up to 4–5 elements. In fact, the trueness and precision obtained with the optical impressions for these types of short-span restorations are comparable to those obtained with conventional impressions. However, optical impressions do not appear to have the same accuracy as conventional impressions in the case of long-span restorations (FULL MOUTH RESTORATIONS)

SCANNING EFFICIENCY

Scanning efficiency can be divided into three parts: **speed**, **acquisition**, **intelligence**.

SPEED:

Scanning speed is certainly a matter of great importance for an IOS. IOS have different scanning speeds, and the latest-generation devices are generally faster than the oldest ones. However, the literature has not clarified which device can be more efficient: in fact, the scanning speed does not depend only on the device, but largely on the experience of the clinician.[14]

ACQUISITION AND INTELLIGENCE:

IOS should be able to fit in an 'open' workflow and should have an affordable purchase and management price. Ideally, an IOS should have two outputs: a proprietary file with legal value and an open-format file (e.g... STL, OBJ, PLY). Open-format files can be immediately opened and used by all CAD prosthetic systems. In such cases, the literature generally refers to an 'open system'. The advantage of these systems is versatility, together with a potential reduction of costs (there is no need to buy specific CAD licenses or to pay to unlock the files); however, a certain degree of experience may be required, initially, to interface the different software and milling machines.[15] This problem does not arise in the case of IOS within a 'closed system'. Such scanners have as output only the reference proprietary (closed) file, which can be opened and processed only by CAD software from the same manufacturing company. The inability to freely dispose off STL files, or the need to pay fees to unlock them, certainly represents the main limits of closed systems. However, the inclusion within an integrated system may encourage workflow, especially in the case of less experienced users. In addition, some closed systems offer a complete, fully integrated digital workflow, from scanning to milling, and provide chair-side solutions. Finally, converting files (e.g. the conversion of proprietary files to open formats) may result in loss of quality and information.[17]

Comparison criteria for the evaluation of intraoral scanners

In order for the comparison to be made in the same way, the tests of the intraoral scanners have been carried out using different types of teeth, with full arch scans and also bite scans.[18-20]
In order to offer a graphical score, 5 stars were used, so the more stars an intraoral scanner has in one of the criteria, the better. Here is what the comparison criteria were and why:

- **Scanning speed:** One of the most important factors when choosing an intraoral scanner is the speed of the scan. Therefore, the first thing that doctors take into account for the development has been the speed of full arch scanning. Although the evaluation is relative, the five star rating gives an idea of which ones are faster or slower.
- **Scanning flow:** not only the speed of the scan is relevant, but also how smooth the experience is. Whether the intraoral scanner handles well in the corner and anterior region,

or recovers quickly after losing the scan. Also if it joins the images well or if it loses frequency. The assessment of the scan flow, indicates which experience has been irregular or in any case, the lack of response.

- **Intraoral scanner size:** Not only the size of the intraoral scanner head was taken into account, but also the weight and overall size. Although, judging from the overall size, some scanners are heavier and more complicated than others. The focus has been on ergonomics, weight and overall, how comfortable the scanner feels in the hand and when scanning.
- **Ease of use:** this criteria takes into account both the hardware and the way the software was managed or if there were any problems with scanning, processing and general workflow.
- **Intraoral scanner price:** Another criteria that dentists consider quite important is the price.Since this can vary, depending on the input cost, complements distributors, software charges, cloud data for the storage of scanned files and geographical location. No exact numbers are provided, but a relative comparison based on the most expensive and least expensive scanners.
- **Subscription requirements and maintenance packages:** The subscription requirement for the use of the intraoral scanner may be mandatory, recommended or not required. The assessment has been made on this basis, as some companies claim that they do not require any kind of subscription, but this is sometimes not entirely true. Many have some kind of annual subscription for support and maintenance and others even require a subscription to be able to use them.
- **Open or closed scan export:** all scanners are now open (more or less), which allows to export at least one of the following source files STL, OBJ and/or PLY; however, they did not take this criteria into account for the evaluation.
- **Autoclave scanning tips:** If the tips can be autoclaved and how many cycles can be completed before replacing them. But if this feature is there, its an important asset in maintaining sterlisation protocols in clinic
- **Touch screen:** the intraoral scanners connected to the trolleys are actually screen-touch. This does not apply to those connected to a laptop via a USB port as the screen will work as a touch screen, but not all the software was designed with touch interaction in mind and can be better handled with a mouse and keyboard.
- **Wireless scanner:** the assessment is based on whether or not wireless options are available for the scanner.
- **Caries detection:** this criterion is based on whether or not the intraoral scanner has caries detection function such as transillumination or fluorescence.
- **CAD Integration:** One may wonder if the scanner has integrated CAD/CAM design functions. If not, clinician will have to export the files and the prostheses will have to be designed in third-party software such as Exocad.

CEREC Primescan

- The intraoral scanners Primescan DENTSPLY Sirona has a very fast scanning speed.
- It's clearly the fastest scanner on the market.
- As for the scan flow, it is extremely smooth. It provides one of the smoothest scanning experiences and does not delay compared to all other scanners.
- The **Primescan** scanner is large and bulky as compared to the Omnicam which was supposed to be one of the smallest.
- To control cross infection, two stainless steel scanning tips have been launched, one is autoclavable and the other is not. A single-use plastic scan tip is also available.
- As well as being the fastest intraoral scanner, it is also the heaviest (457g or 524g, depending on the scanner cover you use). The Omnicam, weighed 316 gr.
- Does not have caries detection functionality.
- The heater/fan is now the same as most scanners on the market, it is no longer in the trolley and is now internal.
- The scanner still remains connected to the trolley;however the trolley is wireless and can be used without connection for at least 60 minutes.
- Data processing is very good, so it requires little or no waiting time between scans.
- The trolley has improved the screen size, is larger than the Omnicam and is also touch-sensitive. Similarly, they have replaced the tracking ball with a touch pad.
- The user interface now looks much more elegant and modern.

Efficiency

- **SPEED**: Scanning traversal speed was definitely one of the fastest as compared to all the other scanners.

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- **ACQUISITON**: Data capture also feels significantly faster than the Trios 4 and the Omnicam in a single pass, thanks to the Primescan's large scanner head and depth of field.
- **INTELLIGENCE**: The AI powering the Primescan is simply amazing. Its ability to fix soft tissues, and other mistakes, makes for scanning experience that is significantly less stressful.

3Shape Trios 4

- The intraoral scanner **TRIOS 4** by **3Shape** is one of the fastest in the market, although it has the same speed as the TRIOS 3, it has considerable improvements in both hardware and software and functionality.
- It has a modern and stylish design.
- A full arch scan is performed intra-orally in just 25 seconds.
- For caries detection, a second scan is required which is overlapped with the digital model. This is done through the fluorescence technology incorporated in the scanner. A color map shows areas of fluorescence in which there may be active caries sites. In addition, they will soon launch a scanning tip for the detection of interproximal caries that will be carried out by means of transillumination
- It has intelligent scanning tips, so there is no need to wait for it to warm up to start working.
- It's the only intraoral scanner with a completely wireless option.
- It provides smart advice that lets you know how many times it has been sterilized. Recommended 150 cycles maximum before replacement.
- They have improved battery life by 30%.
- The scope of the TRIOS 4 has been improved, including clear aligners, dentures, sleep aids and splints.
- The wireless model of the scanner can be plugged in and used if the battery runs out.

Efficiency

- **SPEED**: The new Trios 4 is faster than Trios 3, but technical data availableweren't able to pinpoint exactly what made them faster, other than "new hardware and software".
- **ACQUISITION**: Data capture was on par with the Omnicam in a single pass, and has an added advantage as compared to it
- **INTELLIGENCE**: The AI was very impressive but not as aggressive as the AI in the Primescan. I actually had a special opportunity to scan a live person with the Trios 4, and it was able to remove most, but not all, of the soft tissue interference. Unfortunately, we were supervised and not allowed to film this extra test.

What's the difference between Trios 4 and Trios 3? In terms of the core scanning capability, Trios 4 is essentially the same as the Trios 3, but with a bigger battery (if wireless), new scanning tips, and caries detection. During the exhibition, we were told by a sales rep that the Trios 4 is faster and more accurate than the Trios 3, but we couldn't find anything to support that claim.

Medit i500

- The **i500** by Medit provides a scanning experience that rivals some of the best scanners on the market and at a fraction of the price.
- It's one of the lightest intraoral scanners on the market (276gr).
- Basic structural quality but does not affect its performance in any way, only that compared to its competitors, these tend to have more materials and colors.
- Affordable, no subscription cost.
- Allows you to export scanned files in STL, OBJ, PLY formats.
- The first 20GB are free, after that, you can use it by paying the cost of using the cloud.
- It updates incredibly fast. Almost once a month, it is optimized or something is added.
- The team behind Medit is almost always available to help solve problems online.
- The scanner requires an online connection to operate. Although it has an offline mode that can be used offline for about 2 weeks.

Efficiency

- **SPEED**: Very impressive scanning speed on the model.
- **ACQUISITION**: The small scanner head means less data capture overall on every pass. The capture speed makes up for this deficiency and is very smooth, but seems to be missing a bit more data than 3Shape and CEREC scanners.

INTELLIGENCE: We sometimes ran into stitching problems if we didn't follow the recommended scanning strategy

Dental Wings Virtuo Vivo

- **Virtuo Vivo** by **Dental Wings** is an update from the previous version of Dental Wings.

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- It is the only one with a pen-like design, very small when held, making it one of the lightest on the market.
- The hardware has changed quite a bit.
- Scans in full color.
- The scanner does a good job, it can pick up where it left off when scanning is paused and generally has a smooth scanning experience, and however it is not very fast.
- Has a preferred connection to software integrated Clear Correct aligners, similar to iTero and Invisalign.
- It has its own software to design restorations and this seemed to work well for a single restoration. It is quite limited in the tools available when compared to other systems. (For example, Exocad).

Efficiency

- **SPEED**: The maximum travel speed was surprisingly fast on the Virtuo Vivo. It's not at the Medit or 3Shape level, but it's definitely one of the faster and smoothest Tier 2 scanners we tested.
- **ACQUISITION**: The scanner was able to capture most of what its camera saw, and the scanning field also seemed a bit bigger than average.
- **INTELLIGENCE**: The software was able to fix basic stitching issues. The live demonstration also showed how it was able to remove some software interference by repeatedly scanning over the same area.

Table1: Advantages and Disadvantages of optical impressions with respect to conventional impressions

Advantages	Disadvantages
Less patient discomfort	Difficulty detecting deep marginal lines of prepared teeth
Time-efficient	Learning curve
Simplified clinical procedures	Purchasing and managing costs
No more plaster casts	
Better communication with the dental technician	
Better communication with patient	

II. CONCLUSION

To date, only a few studies have compared the trueness and precision of different IOS. Almost all are in vitro studies based on models, as it is currently not possible to calculate the trueness of IOS in vivo; in addition, these studies have quite different experimental designs. Some focused on the accuracy of the IOS in dentate models, while others evaluated the accuracy of the IOS in oral implantology. Regardless, the upshot of these studies is that different IOS have different accuracy; therefore, some devices seem to have more indications for clinical use (for making impressions for fabricating long-span restorations) while others appear to have more limited clinical applications (for making single or short-span restorations).[21-22] It is exceedingly difficult to compare the results (in terms of trueness and precision) of these studies, as scanners have different image-capture technologies and may therefore require different scanning techniques; unfortunately, little is known about the influence of scanning technique on the final results.[21]

Trueness and precision, however, are not the only elements that can differentiate the devices currently available commercially. A whole series of elements (necessity of opacization with powder, scanning speed, tip size, ability to detect in-color impressions) differentiate IOS in terms of their clinical use.

Scanning speed is certainly a matter of great importance for an IOS. IOS have different scanning speeds, and the latest-generation devices are generally faster than the oldest ones. However, the literature has not clarified which device can be more efficient: in fact, the scanning speed does not depend only on the device, but largely on the experience of the clinician.[22]

The size of the tip plays an important role especially when scanning second and third molar. A scanner with a small head is preferred as it is eased its way in scanning; however the scanners with the broad tips also eased its way in scanning posterior area by increasing the area of scanning.[23]

The possibility of getting colored 3D models after scanning is the latest innovation. However The information on color is meaningful especially in communication with the patient, and is therefore of less clinical importance

Finally an IOS should fit in an OPEN workflow, which means the operator should be able to retrieve a file in STL format. The most of the milling machines currently available in market are able to process this format which means operator can get the work processed wherever he wants.[24]

The present review has numerous limitations, as it is only a narrative review, and more systematic reviews of the literature are certainly needed to draw more specific conclusions about the versatility, accuracy and clinical indications of different IOS machines in prosthetic and implant dentistry as well as in orthodontics. Further randomized controlled studies on the use of IOS are needed to be able to perform a systematic analysis of the literature.

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