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Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study

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Abstract

Background: Until now, only a few studies have compared the ability of different intraoral scanners (IOS) to capture high-quality impressions in patients with dental implants. Hence, the aim of this study was to compare the trueness and precision of four IOS in a partially edentulous model (PEM) with three implants and in a fully edentulous model (FEM) with six implants.

Methods: Two gypsum models were prepared with respectively three and six implant analogues, and polyether-ether-ketone cylinders screwed on. These models were scanned with a reference scanner (ScanRider®), and with four IOS (CS3600®, Trios3®, Omnicam®, TrueDefinition®); five scans were taken for each model, using each IOS. All IOS datasets were loaded into reverse-engineering software, where they were superimposed on the reference model, to evaluate trueness, and superimposed on each other within groups, to determine precision. A detailed statistical analysis was carried out.

Results: In the PEM, CS3600® had the best trueness (45.8 ± 1.6μm), followed by Trios3® (50.2 ± 2.5μm), Omnicam® (58.8 ± 1.6μm) and TrueDefinition® (61.4 ± 3.0μm). Significant differences were found between CS3600® and Trios3®, CS3600® and Omnicam®, CS3600® and TrueDefinition®, Trios3® and Omnicam®, Trios3® and TrueDefinition®. In the FEM, CS3600® had the best trueness (60.6 ± 11.7μm), followed by Omnicam® (66.4 ± 3.9μm), Trios3® (67.2 ± 6.9μm) and TrueDefinition® (106.4 ± 23.1μm). Significant differences were found between CS3600® and TrueDefinition®, Trios3® and TrueDefinition®, Omnicam® and TrueDefinition®. For all scanners, the trueness values obtained in the PEM were significantly better than those obtained in the FEM. In the PEM, TrueDefinition® had the best precision (19.5 ± 3.1μm), followed by Trios3® (24.5 ± 3.7μm), CS3600® (24.8 ± 4.6μm) and Omnicam® (26.3 ± 1.5μm); no statistically significant differences were found among different IOS. In the FEM, Trios3® had the best precision (31.5 ± 9.8μm), followed by Omnicam® (57.2 ± 9.1μm), CS3600® (65.5 ± 16.7μm) and TrueDefinition® (75.3 ± 43.8μm); no statistically significant differences were found among different IOS. For CS3600®, For CS3600®, Omnicam® and TrueDefinition®, the values obtained in the PEM were significantly better than those obtained in the FEM; no significant differences were found for Trios3®.

Conclusions: Significant differences in trueness were found among different IOS; for each scanner, the trueness was higher in the PEM than in the FEM. Conversely, the IOS did not significantly differ in precision; for CS3600®, Omnicam® and TrueDefinition®, the precision was higher in the PEM than in the FEM. These findings may have important clinical implications.

Keywords: Intraoral scanners, Oral implants, Accuracy, Trueness, Precision

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Background

Intraoral scanners (IOS) are powerful devices used for optical impressions, and are able to collect information on the shape and size of the dental arches (or the position of dental implants) through the emission of a light beam [1, 2]. In fact, they project a beam or light grid (structured light or laser) onto the tooth surface (or implant scanbodies), and capture, through high-resolution cameras, the distortion that such a beam or grid undergoes when they hit these structures [1, 2]. The information collected by these cameras is processed by powerful software that reconstructs the three dimensional (3D) model of the desired structures [2, 3]. In particular, from the genesis of a "cloud of points" a polygonal mesh is derived, representing the scanned object; the scan is further processed to obtain the final 3D model [2, 3].

The conventional physical detection of impression with trays and materials (alginates, silicones, polyethers) represents a moment of discomfort for the patient [4, 5]; this is particularly the case with sensitive subjects, for example those with a strong gag reflex [6]. In addition, it can be difficult for the clinician, especially in the case of technically complex impressions (for example for the fabrication of long-span implant-supported reconstructions) [5, 7]. The optical impression with IOS solves all these problems: it is well tolerated by the patient, since it does not require the use of conventional materials, and is technically easier for the clinician [4, 8, 9].

The use of an IOS allows the immediate determination of the quality of the impression; virtual 3D models of patients are obtained, which can be saved on computer without physically pouring a plaster model [2, 7, 10]. This saves time and space, and it provides the ability to easily send the models to the laboratory using e-mail, reducing time and costs [2, 7, 9, 10]. The clinician can save money each year on the purchase of impression materials, the fabrication of individual trays, and on casting and shipping of plaster models; it is possible to store virtual models of patients without having to dedicate them a space within the clinic [2, 7, 9, 10]. Not least, the clinician can have a powerful marketing tool for more effective communication with the patient.

To date, IOS are used to obtain study models [11], in prosthesis for the detection of impressions necessary for the modeling and fabrication of a whole series of restorations (single crowns [12], fixed partial dentures [13, 14], and in selected cases, complete fixed arches [15]), but also in the surgical field (integrated in acquisition procedures in guided surgery) [16] and in orthodontics (for the fabrication of aligners and different customized orthodontic devices) [17].

This breadth of applications, together with the undoubted advantages deriving from the use of IOS, have led in recent years to great interest in these machines [2, 3]. Consequently, the industry offers every year new devices, with different features: the widest choice and differences between the various machines can complicate the choice for the clinician [1].

Beyond the operational and clinical differences (speed of use, need of powder, size of the tips) and cost (purchase and management) between different machines, the most important element to be considered should be the quality of the data (mathematics) derived from scanning, defined as "accuracy" [18, 19].

Accuracy is the combination of two elements, both important and complementary: "trueness" and "precision" [18, 19]. The term "trueness" refers to the ability of a measurement to match the actual value of the quantity being measured [19]. An IOS should therefore be able to detect all details of the impression and to generate a virtual 3D model as similar as possible to the initial target, and that little or nothing deviates from reality. In order to detect the trueness of a 3D model derived from intra-oral scanning, it is mandatory to have a reference model with error tending to zero, obtained with industrial machines (coordinate measuring machine - CMM or articulated arms) or with powerful industrial desktop scanners [19]. In fact, only the superimposition of the 3D models obtained with an intraoral device to a reference model (probed with CMM or scanned with powerful desktop machine), through the use of specific software, allows us to evaluate the actual trueness of an IOS [19–21]. Although trueness is the key element for an IOS, it is not sufficient, as it must be accompanied by precision. Precision is defined as the ability of a measurement to be consistently repeated: in other words, the ability of the scanner to ensure repeatable outcomes, when employed in different measurements of the same object [14, 15, 19, 20]. The constant repeatability of the result is of great importance: different measurements of the same object must necessarily be comparable, and differ from each other as little as possible. To measure the precision of an IOS, no reference models are needed: it is sufficient to superimpose different intraoral scans between them, and evaluate to what extent they deviate, using dedicated software [14, 15, 19].

Unfortunately, very few studies in the literature have evaluated the accuracy of the different IOS available on the market [19, 20, 22–26]. The available studies mostly report on first-generation scanners [20, 23–26], and do not deal with the most powerful and recent devices: scientific literature is not as fast as the industry. Moreover, only a few studies have compared the ability of different IOS to capture high-quality impressions in patients with dental implants [19, 26–28].

Therefore, the aim of the present study was to compare the trueness and precision of four of the most recent and powerful IOS, in two different situations: in a partially edentulous maxilla (PEM) with three implants and in a fully edentulous maxilla (FEM) with six implants.

Methods

The models

Two different gypsum models were prepared, representing two different clinical situations. The first gypsum model was a partially edentulous maxilla (PEM), with three implant analogues (BT Safe Int®, BTK-Biotec Implants, Povolaro di Dueville, Vicenza, Italy) in positions #23, #24 and #26; the second gypsum model was a fully edentulous maxilla (FEM), with the same implant analogues in positions #11, #14, #16, #21, #24 and #26 (Fig. 1). After that, nine high-precision non reflective polyether-ether-ketone (PEEK) scanbodies (BT Scanbodies®, BTK-Biotec Implants, Povolaro di Dueville, Vicenza, Italy) were selected. This material was chosen for its optical properties, because it does not reflect light [29]: it is, in fact, well known that IOS may have difficulties scanning reflective, shiny surfaces [3]. These high-precision PEEK cylinders were screwed on the implant analogues, and the models were ready for the evaluation.

Study design

Four different IOS (CS 3600®, Carestream, Rochester, NY, USA; Trios 3®, 3-Shape, Copenhagen, Denmark; Cerec Omnicam®, Sirona Dental System GmbH, Bensheim, Germany; True Definition®, 3M Espe, S. Paul, MN, USA) were compared in this study (Fig. 2), with the purpose to investigate their trueness and precision in oral implantology. The reference scanner for trueness measurements was an industrial optical desktop scanner (ScanRider®, V-GER srl, Bologna, Italy). The study design was as follows: first, the gypsum models (PEM and FEM) were scanned with the reference scanner, and three scans were taken for each model. All generated datasets were imported into powerful reverse-engineering software (Geomagic Studio 2012®, Geomagic, Morrisville, NC, USA) and superimposed on each other, in order to select one reference dataset (reference model, R1) for the PEM and FEM. The R1 models were then used as references for the trueness measurements of all IOS. In brief, the two gypsum models were scanned with the four IOS. Five scans were then taken for each model, using each different device. The scanning sequence was randomized, in order to reduce the potential negative effects of operator fatigue; the scans were taken sequentially, with an interval of 10 minutes, in order to allow the operator to rest and the device to cool down. A zig-zag scanning technique was followed in all cases, and for each intraoral scanner: starting from the first quadrant (superior right), the tip of the scanner draws an arc movement, from vestibular to palatal and back, slowly moving forward so that teeth, scanbodies and gingiva were scanned from vestibular to palatal (and back), passing over the occlusal plane. In the present study, all IOS were used under the same conditions (in the same room, with a temperature of 20°, humidity of 45%, and air pressure of 760 ± 5 mmHg) by the same dentist with long experience in digital dentistry and intraoral scans.

The scanners

All information about the reference scanner and the four IOS used in the present study are provided here; the main features of the four IOS are also summarized in Table 1.

ScanRider® (V-GER srl, Bologna, Italy)

The reference scanner used in the present study was an industrial optical desktop scanner, working under the principle of structured light active triangulation. The device was configurable and composed of four parts: the optical assembly, the 1 or 2° of freedom mechanics, the electronics and the software. ScanRider® features a DLP 600il projector, B/W 1.3 Megapixel cameras and a

Fig. 1 Two different gypsum models were prepared: a partially edentulous maxilla, with three implant analogues in positions #23, #24 and #26, and a fully edentulous maxilla, with the same implant analogues in positions #11, #14, #16, #21, #24 and #26

Fig. 2 Four different IOS (CS 3600®, Carestream, Rochester, NY, USA; Trios 3®, 3-Shape, Copenhagen, Denmark; Cerec Omnicam®, Sirona Dental System GmbH, Bensheim, Germany; True Definition®, 3M Espe, S. Paul, MN, USA) were compared in this study, with the purpose to investigate their trueness and precision in oral implantology

working distance of 120 mm. It has a standard resolution of 25–50 μm, an average error (accuracy) of 5–10 μm, a precision (standard deviation) of 15–30 μm, a number of triangles for each scan up to 2,500,000 and a free output format (. STL).

CS 3600® (Carestream, Rochester, NY, USA)

CS 3600® is the second IOS produced by Carestream. It was launched in 2016, and improved based on feedback from the first one, CS 3500® (which was available on the market since 2014). These two IOS differ significantly in the technology of acquisition because CS 3500® used the principle of optical triangulation and generated individual images, while CS 3600® works according to the principle of the active speed 3D video. Both these scanners are available in a USB version, in which the device has a direct connection with the laptop via USB cable; however, the integration of the scanner into the treatment unit has been planned. CS 3600® is a powerful structured LED light scanner; it does not require powder and is able to provide high-quality color images. Such images are a valuable aid in identifying the margin line, when scanning natural teeth. The scanner comes with different sized tips for scanning the frontal and posterior areas. CS 3600® is extremely fast as it allows quick scanning of both jaws, the software acquisition is powerful (in the present study, we have used the software version 1.2.6, released in 30-05-2016) and features a highly intuitive graphical interface. CS 3600® is an open scanner because its produces proprietary files (. CSZ) but also open files (.PLY, STL) that can be opened from any computer assisted design (CAD) software. The use of proprietary files (.CSZ) allows the maintenance of color information, within a dedicated workflow, which involves modeling with proprietary CAD software (CS Restore®) and the subsequent manufacture of a whole series of simple restorations (inlays, onlays, veneers, single crowns and small bridges) with the dedicated in-house milling machine (CS 3000®). On the other hand, the free files (.PLY,.STL) generated by CS 3600® without paying any fee (either monthly or yearly), can be easily opened with any CAD software on the market and therefore manufactured with any milling machine. Therefore, there are no restrictions on the use of such files by laboratories. Through the conventional laboratory workflow, the data acquired from CS 3600® can be used for the manufacture of more complex restorations, such as structures with multiple elements, also supported by implants, as well as frameworks and bars.

Trios 3® (3-Shape, Copenhagen, Denmark)

Trios 3® is the third IOS fabricated by 3-Shape, after Trios Standard® (2011), which produced monochrome images, and Trios Colour® (2013). Trios 3® was presented in March 2015 at the International Dental Show (IDS) meeting in Cologne, and then launched on the market

Table 1 The four IOS used in this study

	Technology of acquisition	Powder	Colour	System
CS 3600®	Active speed 3D video	No	Yes	Completely open – proprietary files (.CSZ) but also open formats (.PLY,.STL) are immediately available
Trios 3®	Confocal microscopy and ultrafast optical scanning	No	Yes	Closed – only proprietary files (.DCM) are available
Cerec Omnicam®	Optical triangulation and confocal microscopy	No	Yes	Closed – proprietary files (.CS3,.SDT,.CDT,.IDT) are available, but with the possibility to obtain open formats (.STL) with Cerec Connect®
True Definition®	Active wavefront sampling 3D video technology	Yes	No	Closed – proprietary files are available, but with the possibility to obtain open formats (.STL) with 3M Connection Center®

from May 2015 in three different versions: a trolley version with a touch-screen, a version incorporated into the dental treatment unit, and a USB version. This latter version allows the clinician to use a laptop, into which the scanner is plugged via a USB port; however, this connection is not direct (it requires several connecting cables) and therefore the scanner is not easily transportable. In the last IDS meeting in March 2017, a new wireless version of TRIOS 3® was presented: in this last release, the IOS will connect via Wi-Fi to a laptop or to the traditional cart, eliminating the need for a connecting cable between the scanner wand and the computer. All the aforementioned versions are available with a straight pen-grip handle or with a pistol-shaped handle (320 x 56 x 16 mm). Trios 3® is a powerful and extremely fast structured light scanner. It works under the principle of confocal microscopy and ultrafast optical scanning; it is powder-free and it produces high-quality in-colour images. The scanner has special features integrated, such as the Real Colour Scan®, HD Photo Function® and Digital Shade Determination®: these are interesting because colour scanning can help to differentiate the natural tooth structure and the gingival tissues, and therefore it may help dentists to identify the margin lines. The acquisition software of Trios 3® (in the present study, the software version 16.4 has been used) has automatic artefact elimination and advanced cutting functions, combined with smart blocking functions available for surfaces: the latter feature is very useful when scanning natural teeth, to lock the dental margins highlighted immediately after removal of the retraction cord, and thus avoid overwriting of it. Trios 3® has a big wand, but this is not a limitation because this tip can be used to avoid scanning of unwanted tissues (tongue, cheeks, lips). Like the previous versions, Trios 3® produces proprietary files (.DCM) which can be opened only by the 3-Shape computer-assisted-design (CAD) software (3-Shape Dental System®), via the proprietary cloud-based platform (Trios Inbox®) or setting up a direct connection via Direct Connect®, through which data are fed into the dental system and read out from there. The 3-Shape Dental System® CAD software is extremely powerful and widespread in dental laboratories worldwide. In any case, the scanner does not automatically export files in open formats (.STL,.PLY) readable from other common CAD software: Trios 3® is a closed system; in the present study, therefore, all.DCM files were converted into.STL files using the CAD software Dentalsystem 2016 (version 1.6.3). The CAD software of 3-Shape allows design of all kinds of prosthetic restorations and frameworks (inlays, onlays, veneers, crowns, bridges, bars): in addition, modules for implant (3-Shape Implant Studio®) and orthodontic planning (3-Shape Ortho Analyzer®) are available. However, still 3-Shape has no dedicated milling machines for in-office, chairside restorations.

Cerec Omnicam® (Sirona, Bensheim, Germany)

Cerec Omnicam® is the last and more powerful of Sirona IOS and it represents the technological evolution of the previous devices (Cerec Bluecam®, available since 2009, and Apollo DI®). Cerec Omnicam® was introduced onto the market in 2012 and is currently available in two different versions: a trolley (Cerec Omnicam® AC) and a tabletop version (Cerec Omnicam® AF). It is a structured light scanner that uses a white LED and it works under the principle of optical triangulation and confocal microscopy. Cerec Omnicam® is fast, it does not require powder and it offers true-colour information. The dimensions of the scanner (228 x 16 x 16 mm) are limited and the tip is not too big, therefore it is easier to scan the posterior areas (maxillary or mandibular third molars). The acquisition software is powerful and it will be further improved with a series of new tools in the last release presented at the recent IDS meeting in Cologne (2017). With Cerec Omnicam®, the digital workflow can take place directly at the chairside, using the proprietary CAD software, or via the cloud-based platform (Cerec Connect®). In fact, Cerec Omnicam® is a closed system, exporting the digital impression data as proprietary files (.CS3,.SDT,.CDT,.IDT) that work only on Sirona's supporting CAD software and CAM devices. Recently, however, the system has been partially opened, and with Connect®, there is the possibility to transform the proprietary files into.STL files, usable from any CAD system. In the present study, in fact, the software Cerec Connect 4.4.4 has been used, and all proprietary files have been converted into.STL using the Inlab software (16.0). With Sirona, the chairside workflow with the newly launched Chairside software 4.4® and the 3 + 1 axis milling machines Cerec MC® (X/XL) is fully established; the labside workflow includes the inLAB15® CAD software and the MC X5® milling unit. The CAD/CAM system of Sirona allows the clinician and the laboratory to design and mill a series of prosthetic restorations and frameworks (inlays, onlays, veneers, crowns, bridges, bars). In addition, Cerec Omnicam® has special scanning software for orthodontic applications (Cerec Ortho®), which allows digital impressions to be submitted to third-party manufacturers, and also dedicated software for guided surgery (Cerec Guide®), enabling the chairside manufacture of surgical templates for implant placement.

True Definition® (3M Espe, St. Paul, MN, USA)

True Definition® is the second IOS fabricated by 3M Espe, as it represents the evolution of the LAVA COS® (which was introduced onto the market in 2008), with data processing algorithms that have been altered in

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