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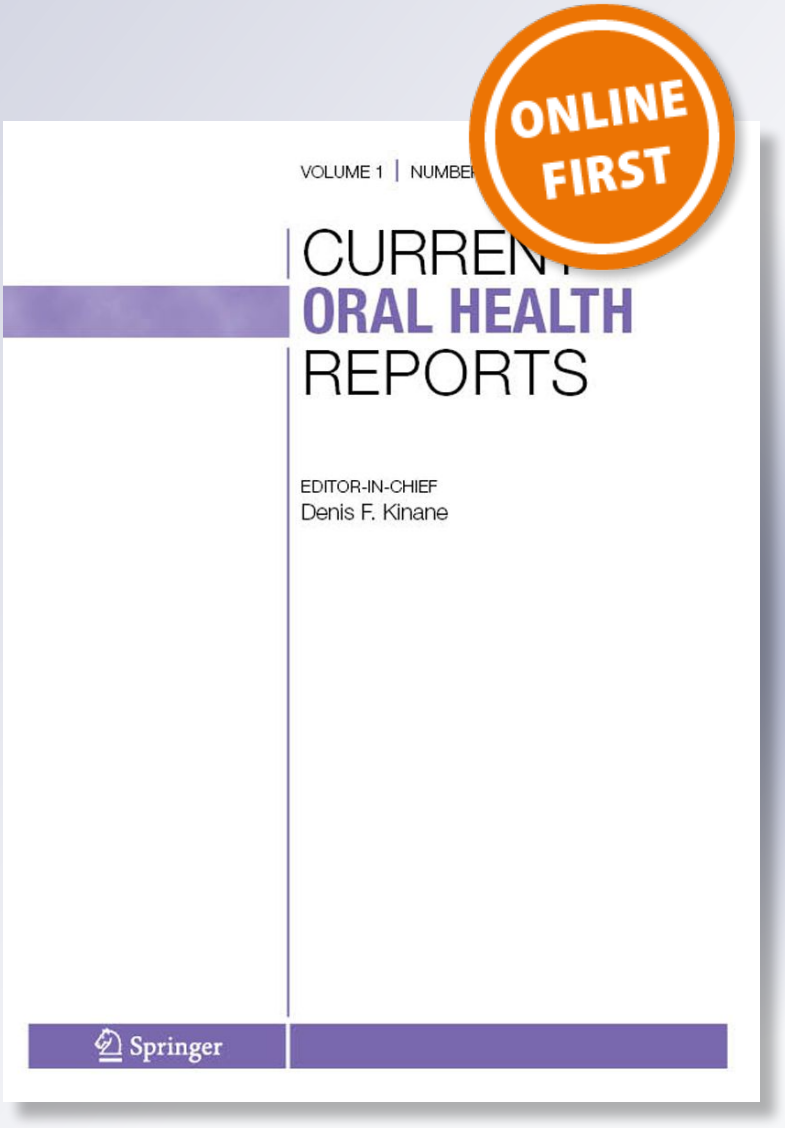

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Accuracy and Reliability of Intraoral Scanners: Are They the Better Option?

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Abstract
Purpose of Review The aim was to compare the accuracy of digital intraoral impressions with conventional impressions on the fabrication of different types of restorations. This study also compared the accuracy, reliability, and ease of use of different types of intraoral scanners available and correlated the results with the different scanning technologies.
Recent Findings Digital impressions offer the same level of accuracy as conventional impressions regarding fabrication of crowns, fixed dental prostheses (FDPs), implant-supported crowns, and short-span FDPs with marginal gap values within the clinically acceptable range (<120 μm). However, for full-arch restorations, conventional impressions result in better accuracy.
Summary Further enhancements needs to be undertaken regarding intraoral scanners to improve its accuracy regarding fabrication of full-arch restorations. Further in vivo studies evaluating the accuracy of intraoral digital impressions on the fabrication of a wider range of restorations such as inlays, veneers, and full-arch restoration need to be conducted.

This article is part of the Topical Collection on *Dental Restorative Materials*

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Keywords CAD/CAM · Digital dentistry · Marginal gap · Intraoral scanners · Digital impressions

Introduction

Electronic technology, digital technology, and advanced manufacturing has been applied in dentistry and gaining popularity in its various fields including prosthodontics, orthodontics, implant dentistry, and oral and maxillofacial surgery [1, 2]. Computer-aided design and computer-aided manufacturing (CAD/CAM) have been used in the fabrication of ceramic restorations and fixed dental prostheses (FDPs), since the 1980s [3]. Many CAD/CAM systems are now available for design and fabrication of restorations based on conventional silicone impressions [4]. In these cases, a plaster cast is made from the silicone impression and then scanned using an extra-oral desktop scanner. Although the accuracy of extra-oral scanning is adequate, the intraoral outline depictive process of a conventional impression is hard to perfectly reproduce due to the deformation of impression materials and plaster. Therefore, the inadequate precision of plaster casts is not optimal for completing CAD/CAM procedures [5•]. In contrast, direct intraoral digital impressions can avoid errors more than a conventional impression can. Additionally, this saves time for making conventional impressions and plaster models and lowers the cost of materials [6].

An intraoral scanner collects information about projecting light. Reproducible tissues are then showed on the hardware display as natural looking. They are used to acquire 3D data concerning the prepared teeth, the adjacent teeth, and the occlusion with the opposing dentition. The intraoral scanner measures the light reflection times of the subject surface. The description, based on data and calculation algorithms to copy the software, calculates and generates a computer screen

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image of the prepared area [7•]. Intraoral scanners use video technique or still photo technique for scanning. Still images are based on triangulation or parallel confocal laser scanning in which these images are stitched together to form a 3D reconstructive image. Confocal laser scanning microscopy (CLSM) is a technique to acquire in-focus images from selected depths, a process known as optical sectioning (high-resolution optical images with depth selectivity). Point-by-point images are obtained and reconstructed by a computer. This technique can reconstruct the surface profile of opaque specimens and obtain the interior imaging of non- opaque specimens. Unlike a conventional microscope which sees as far into the specimen as the light can penetrate, the confocal microscope only images one depth level at a time. The CLSM achieves a controlled and highly limited depth of focus. In active triangulation methods, a light radiation is projected on to the scene, and its reflection is acquired in order to calculate the position of the target object [8•].

These are the basic principle, and in addition to this, each manufacturer uses its own technique. Intraoral scanners may also use multiple techniques for data collection. Lava C.O.S. (3 M ESPE, St. Paul, MN) and Lava True Definition scanner (3 M ESPE) use active wavefront sampling for data collection from which video image is formed. CEREC AC Bluecam (Sirona Dental System GmBH, Bensheim, Germany) uses active triangulation and optical microscopy to produce still images. The CEREC AC Omnicam (Sirona Dental System GmBH) CAD/CAM system uses video for data collection. iTero (Cadent, Carlstadt, USA) and 3Shape Trios (Copenhagen, Denmark) use the parallel confocal method to produce digital data [8•, 9, 10••]. Some scanners also such as Lava C.O.S., Lava True Definition, and AC CEREC Bluecam require a coating material to be sprayed on the tooth structure for imaging [8•].

Good marginal and internal fit are considered two of the most important factors in improving the prognosis of ceramic restorations [11]. A reduced marginal gap prevents plaque accumulation, bacterial adhesion, and the risk of formation of secondary caries. Most investigators use the marginal gap criteria stated by McLean and von Fraunhofer, who concluded that a maximum of 120 μm is allowed for marginal opening. Values between 50 and 200 μm are reported with the absence of an objectively accepted threshold [12–14].

The accuracy of dental impressions is determined by the trueness and precision values, which together describe the accuracy of a specific impression method. The trueness is determined by the deviation of the tested impression method from the original geometry. Precision indicates the deviations between the impressions within a test group. In previously published studies, linear distance measurements were used to evaluate the trueness of dental impressions [15, 16]. However, this method is limited by the lack of clear reference points and the inability to measure repeatable reference points. Another technique to investigate the accuracy of dental models was attempted by analyzing surface points with high trueness by coordinate measuring machines (CMMs) [17]. Due to the inability of CMMs to scan in interproximal areas and fissure lines, the geometric size and shape of the testing object were limited and dissimilar from the typical morphology of teeth or the dental arch.

Considering the limitations of these previously utilized measurements of accuracy, a different method was developed. To compare the accuracy of the digital and conventional workflows, a reference scanner was used to obtain the surface tessellation language (STL) datasets of the models created using each method and of the original master model from which both types of impressions were taken. Comparing the STL datasets from each workflow to the STL from the original model allows for comparison of the accuracy and trueness of each technique. Comparison is made possible by utilization of software which superimposes each model scan with the master scan individually using a best-fit algorithm [7•, 18, 19].

There are still several obstacles and deficiencies to address regarding intraoral digital impressions. The use of a coating medium or the scanner displacement during scanning might affect scanning accuracy. This article reviews the characteristics of some major intraoral digital impression devices currently available and focuses on their accuracy regarding fabrication of different type of restorations, difficulty of manipulation, and operator's perception.

Digital Impression versus Conventional Impression for Fabrication of Crowns and FDPs

Several studies have investigated the accuracy of single crows and FDPs fabricated from impressions obtained from intraoral scanners. Seelbach et al. [20] in an in vitro study evaluated the fit of single crowns fabricated from the Lava C.O.S. scanner and conventional impressions. They found no differences between the two groups. Zeltner et al. [21] and Berrendero et al. [22] conducted in vivo studies to compare the marginal fit of single all-ceramic crowns fabricated from intraoral digital impressions and conventional impressions. They found no significance difference in the marginal and internal fit between the two techniques with the Lava C.O.S. and the 3Shape Trios scanners showing the lowest values. However, in similar in vivo studies the crowns fabricated using the Lava C.O.S. and the Cadent iTero showed statistically significant better marginal gap values when compared to the conventional impression technique [12, 23••, 24]. While in another in vivo study conducted by Boeddinghaus et al. [25] the iTero, Trios, and True definition intraoral scanners showed comparable marginal gap to conventional impression. However, the CEREC AC Omnicam showed the highest values of marginal gap (149 μm) when compared to the other groups. Although

these studies showed marginal gap values within the clinically acceptable range, the differences in their results might be attributed to the preparation design, material from which the restoration is fabricated, and its milling technique [26–28].

As for FDPs, multiple in vitro studies evaluated the accuracy of impressions obtained from the Trios and Lava C.O.S. intraoral scanners. All studies showed higher accuracy than conventional impressions [13, 29, 30]. However, in an in vivo study by Gjelvold et al. [31], no differences were found between the marginal fit of FDPs fabricated from impressions obtained from the Trios intraoral scanner when compared to the ones fabricated from conventional impressions, but the authors stated that the occlusal contacts and convenience to both clinicians and patients were better with the restorations fabricated using the digital workflow technique.

In this category, the technology of scanning did not influence the final outcome of accuracy and although the CEREC AC Omnicam which uses a triangulation scanning technology showed the least accurate results, its values were still within the clinically acceptable range.

Digital Impression Versus Conventional Impression for Fabrication of Implant-Supported Crowns and FDPs

In an vitro study, Abdel-Azim et al. [32] studied the influence of digital impression techniques on the accuracy of dental implant-based single units and complete arch frameworks. Their results showed that conventional impressions resulted in a less marginal gap than digital impressions for a single-implant framework. For single implants, the mean marginal gap was 24.1 μm for conventional impressions while for digital impressions it was 61.4 μm. In full-arch impressions, a 135.1 μm mean marginal gap was measured for conventional impressions compared to 63.1 μm for the digital impressions. Additionally, Lee et al. [33] conducted an in vitro study to assess the accuracy of implant impressions made with digitally manufactured models vs. gypsum models vs. CAD/CAM system models. The digital impressions were made with the iTero system and the conventional close-tray impressions with silicone impression material. Gypsum models represented more details in grooves and fossae compared to CAD/CAM models. According this study, the authors concluded that milled models based on digital impressions were comparable to gypsum models based on conventional impression.

In another in vitro study, Papaspyridakos et al. [34] evaluated the accuracy of digital and conventional impression techniques for completely edentulous patients. A master model of an edentulous mandible with five implants was fabricated to serve for both implant- and abutment-level impressions. Digital impressions were obtained using Trios intraoral scanner after connecting polymer scan bodies. For the conventional impressions, a splinted and a non-splinted technique were used for implant-level and abutment-level impressions. Master casts and conventional impression casts were scanned using a desktop extra-oral scanner to obtain digital volumes. STL datasets from the five groups of digital and conventional impressions were superimposed with the STL dataset from the master cast to assess the 3D deviations. They concluded that the accuracy of digital impressions was not different than the implant-level, splinted impressions for completely edentulous patients and both more accurate than the implant-level, non-splinted impressions.

Digital Impression Versus Conventional Impression for Full-Arch FDPs

Several studies evaluated the accuracy of intraoral digital impressions for fabrication of full-arch FDPs. Ender and Mehl [18] evaluated the accuracy of conventional and digital impressions of a full-arch dental reference model. Four digital impression systems (CEREC Bluecam, CEREC AC Omnicam, iTero, Lava C.O.S.) and four conventional impression materials were used. A high accuracy exra-oral reference scanner was used to evaluate the accuracy for both full-arch conventional and digital impressions. The results showed that the highest trueness and precision were measured for CEREC Bluecam, vinylsiloxanether, and direct scannable vinylsiloxanether. Local deviations of the full-arch impressions were higher with the digital impression than with conventional impression methods. However, Patzelt et al. [35] evaluated the accuracy of intraoral scanners in full-arch scans. A representative model with 14 prepared abutments was digitized using a model scanner as well as four intraoral scanners (iTero, CEREC AC Bluecam, Lava C.O.S., and Zfx IntraScan). Their results showed that except for the CEREC Bluecam which showed the lowest precision and trueness, all other systems showed comparable accuracy among them.

Kim et al. [36•] determined in another in vitro study the effect of an artificial landmark on a long edentulous space on the accuracy outcomes of intraoral digital impressions. A mandibular model containing four prepared teeth and an edentulous area was used. A blue-light, light-emitting diode model scanner, and three intraoral scanners (3Shape trios, CEREC AC Omnicam, and Kodak Carestream) were evaluated. Five scans were made using each intraoral scanner without an artificial landmark, and another five scans were performed after application of an artificial landmark. Results showed that the artificial landmark had a positive impact on the final accuracy of the scan obtained. The CEREC AC Omnicam showed the least accuracy without the use of the artificial landmark. All scanners showed lower accuracy when compared to the model scanner.

Su and Sun [30] compared the accuracy of intraoral digital impression scanning with the accuracy of extra-oral scanning in different arch spans. A dental model with prepared abutments were designed to form 5 set of arrangements according to the layout of prepared abutments (arrangement 1: single prepared maxillary central incisor; arrangement 2: single prepared maxillary first molar; arrangement 3: prepared central incisor and canine with the lateral incisor absent; arrangement 4: half of upper arch with 7 prepared teeth; arrangement 5: entire upper arch with 14 prepared teeth). Each arrangement was scanned by Trios intraoral digital scanner and the extra-oral scanner for 10 times. They concluded that precision decreases with the increased scanning range. Precision was clinically acceptable when scanning range was less than half arch. Precision of extra-oral scanning was acceptable in scanning any scope of arch region.

In an in vivo study, Flugge et al. [37] evaluated the precision of intraoral digital impressions. Ten full-arch intraoral scans with the iTero CAD/CAM system and ten conventional impressions were taken of one patient. The impressions were poured into plaster casts and the casts were scanned again using the iTero scanner and a desktop extra-oral scanner. The results showed that the lowest precision was measured for iTero scans from the patient while the highest precision was measured for stone model scanning. Extra-oral model scanning with iTero showed a higher precision than the patient's iTero scans.

In this category, it was clearly seen that as the range of scanning became larger, scanners utilizing the triangulation technology were much less accurate than scanner utilizing the CLSM. This might be due to the fact that in CLSM the limited detector aperture obstructs the light which is not coming from the focal point. The out-of-focus light is suppressed thus most of the returning light is blocked by the pinhole, which results in sharper images [8•].

Accuracy and Repeatability Between Digital and Conventional Impressions

Ji-Man Park [10••] conducted a study to evaluate the accuracy of different types of intraoral scanners. A dental model containing five prepared teeth was scanned by the extra-oral scanner and five intraoral scanners: E4D dentist, Fastscan, iTero, Trios, and Zfx Intrascan. The captured images from the scanners were compared with the image from the reference scanner (trueness) and within each scanner groups (precision). The Fastscan, iTero, and Trios showed the highest trueness and precision when compared to the other scanners. According to the restoration type, significantly higher trueness was observed in crown and inlay than in bridge. If compared by the technology of intraoral scanning, there was no significant difference between the still image acquisition and video acquisition groups.

Lee et al. [38], in an in vitro study, compared the accuracy of two types of intraoral scanners using different image impression techniques. A master model was fabricated to replicate a maxillary first molar single-abutment tooth model. The master model was scanned with a high accuracy engineering scanner (control) and with two intraoral scanners (CEREC AC Bluecam and CEREC AC Omnicam). Their results showed that the CEREC Omnicam showed better trueness when compared to the Bluecam. However, both showed similar precision. They attributed the difference in trueness values to the thickness of the coating medium used before scanning by the CEREC AC Bluecam. In a similar study by Guth et al. [39••], they evaluated the accuracy of the 3M true definition, CEREC AC Bluecam, CEREC AC Omnicam, Kodak Carestream, and the ZFX Intrascan intraoral scanners. In this study, the 3M true definition and Kodak Carestream showed the highest accuracy with no difference between the Bluecam and Omnicam and the ZFX intrascan being the least accurate. However, it has to be stated that a titanium testing model was used; therefore, the results of the scanning systems that were used without powder (Omnicam and Zfx Intrascan) can be questioned.

It is clearly seen when comparing different scanners that the scanning mode whether video or still images capture is not the reason behind the differences in accuracies. However, the scanning technology itself is the main factor with the scanners utilizing the triangulation technique with either video or still image capturing modes showing less accuracy when compared to other scanners using different technologies.

Difficulty and Operator's Perception of Digital Versus Conventional Impressions

Several studies have compared the conventional and digital impressions from both the patient's and the dentist's point of view [7•]. In 2014, Yuzbasioglu et al. [40] showed that the overall treatment time and impression time were lower with the CEREC AC Omnicam as compared to conventional methods. Further, Lee et al. [41] evaluated the difficulty level of digital and conventional implant impressions. In this in vitro study, 30 experienced professionals and 30 dental students made impressions of a single-implant model. The student group scored a mean difficulty level of 43.1 for the conventional impression technique and 30.6 for the digital impression technique on a 0 to 100 a visual analog scale (VAS) The clinicians group scored a mean difficulty level of 30.9 for conventional impressions and 36.5 for digital impressions on a 0 to 100 VAS scale. They concluded that the conventional impression was more difficult for the student group than it was for the clinician group. The difficulty level of the digital impression was the same in both groups.

Regarding implant impressions, Joda et al. [42] analyzed the time of impression taking using conventional impressions and the Trios intraoral scanner for single-implant sites. Difficulty and applicability of intraoral scanner was perceived more favorable compared to conventional impressions. They also concluded that for single-implant sites, intraoral scanning was more time efficient than the conventional full-arch impression technique in a phantom head simulating standardized optimal conditions. A high level of acceptance for intraoral scanning was observed among students and dentists.

In an in vivo study, Kim et al. [43] compared the scan time and of the Trios and iTero intraoral scanners among dental hygienists. All learners scanned the oral cavities of four human participants for ten times. The average scan time for ten sessions was greater with iTero than with Trios, but the decrease in the measured scan time was greater \for iTero than for Trios. They concluded that although the learning rate of iTero was rapid, the average scan time for iTero was longer than Trios which was not much influenced by clinical experience.

Conclusions

Based on this review of literature it seems that digital impressions offer the same level of accuracy as conventional impressions in fabrication of crowns, implant-supported crowns, and short span FDPs. However, for full-arch restorations, conventional impressions result in better accuracy.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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