A Comparative Analysis of Intraoral 3d Digital Scanners for Restorative Dentistry

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Abstract

Today, intra-oral mapping technology is one of the most exciting new areas in dentistry since three-dimensional scanning of the mouth is required in a large number of procedures in dentistry such as restorative dentistry and orthodontics. Nowadays, ten intra-oral scanning devices for restorative dentistry have been developed all over the world. Only some of those devices are currently available on the market; the others are still passing the clinical testing stages. All the existing intraoral scanners try to face with problems and disadvantages of traditional impression fabrication process and are driven by several non-contact optical technologies and principles. The aim of the present publication is to provide an extensive review of the existing intraoral scanners for restorative dentistry with particular attention to the evaluation of working principles, features and performances.

INTRODUCTION

The introduction of CAD/CAM concepts into dental applications was the brainchild of Dr. Francois Duret in his thesis presented at the Université Claude Bernard, Faculté d'Odontologie, in Lyon, France in 1973, entitled "Empreinte Optique" (Optical Impression). In detail he developed and patented a CAD/CAM device in 1984. The developed system was presented at the Chicago Midwinter Meeting in 1989 by fabricating a dental crown in 4 hours (1, 2). Digital impressions have been introduced, and successfully used, for a number of years in orthodontics, as well, including Cadent's IOC/OrthoCad, DENTSPLY/GAC's OrthoPlex, Stratos/Orametrix's SureSmile, and EMS'RapidForm but the introduction of the first digital intraoral scanner for restorative dentistry was in the 1980s by a Swiss dentist, Dr. Werner Mörmann, and an Italian electrical engineer, Marco Brandestini, that developed the concept for what was to be introduced in 1987 CEREC® by Sirona Dental Systems LLC (Charlotte, NC) as the first commercially CAD/CAM system for dental restorations (1, 3). Ever since research and development sectors at a lot of companies have improved the technologies and created in-office intraoral scanners that are increasingly user-friendly and produce precisely fitting dental restorations. These systems are capable of capturing three-dimensional virtual images of tooth preparations; from such images restorations may be directly fabricated (using CAD/CAM systems) or can be used to create accurate master models for the restorations in a dental laboratory (1).

Nowadays, ten intra-oral scanning devices for restorative dentistry are available all over the world: four of them are made in USA, two in Israel, two in Germany and one in Italy, in Switzerland and in Denmark. Generally speaking such scanners try to face with problems and disadvantages of traditional impression fabrication process such as, in particular, mould instability, plaster pouring, laceration on margins, geometrical and dimensional discrepancy between the die and the mould. The main advantages in the employment of those devices are: high fidelity models, creation of 3D archives and surgery simulation and a process simplification. Existing devices are driven by several non-contact optical technologies such as confocal microscopy, optical coherence tomography, photogrammetry, active and passive stereovision and triangulation, interferometry and phase shift principles. Basically, all these devices combine some of the cited imaging techniques to minimize the noise source related to the scanning inside an oral cavity as, for example: optical features of the target surfaces (translucency and the different reflectivity of the target materials as teeth, gums, preparations, resins, etc.), wetness and random relative motions. Also several typologies of structured light sources and optical components are employed. The ten existing intra-oral scanning devices for restorative dentistry are listed below:

1. CEREC® – by Sirona Dental System GMBH (DE)
2. iTero – by CADENT LTD (IL)

3. E4D – by D4D TECHNOLOGIES, LLC (US)
4. Lava™C.O.S. – by 3M ESPE (US)
5. IOS FastScan – by IOS TECHNOLOGIES, INC. (US)
6. DENSYS 3D – by DENSYS LTD. (IL)
7. DPI-3D – by DIMENSIONAL PHOTONICS INTERNATIONAL, INC. (US)
8. 3D Progress – by MHT S.p.A. (IT) and MHT Optic Research AG (CH)
9. directScan – by HINT - ELS GMBH (DE)
10. trios – by 3SHAPE A/S (DK)

Only some of these are already commercially available. As already mentioned, even if a lot of advantages in taking digital impressions are attainable, there subsist also some disadvantages related to the existing devices. For example it is often necessary to apply some coatings on the teeth to minimize the noise of the measurement and to rest the camera wand on a tooth to get a steady focus. Moreover, the 3D virtual model is often reconstructed by post-processing single images (acquired from a single perspective); accordingly the reconstruction is not performed in real time with a continuous data capture. Furthermore, data about the accuracy of the available instruments is missing. The aim of the present publication is the evaluation of all these existing devices with particular attention to the working principles they are based on, their features and performances.

STATE OF THE ART AND COMPARATIVE ANALYSIS OF THE TECHNOLOGICAL ALTERNATIVES

CEREC® BY SIRONA DENTAL SYSTEM GMBH (DE)

CEREC® (an acronym for Chairside Economical Restoration of Esthetic Ceramics) was introduced by Sirona Dental System GMBH (DE) in 1987, and it has undergone a series of technological improvements, culminating in the CEREC AC® powered by BlueCam®, launched in January 2009.

Figure 1

Figure 2

Figure 3

Figure 3 - The in-office milling unit (25)

Figure 4

Figure 4 - The CEREC AC BlueCam shorter wavelength blue light source (26)

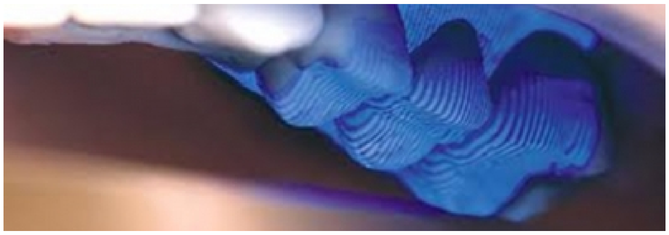
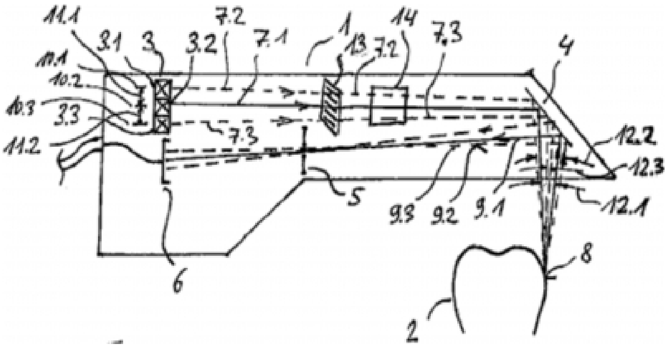


Figure 5

Figure 5 – CEREC scanning system (6)



The latest versions of the CEREC® system (see Figure 1 and 2) are capable of producing inlays, onlays, crowns, laminate veneers, and even bridges and combine a 3D digital scanner with a milling unit (view Figure 3) to create in-office dental restorations from commercially available blocks of ceramic or composite material in a single appointment (1).

The latest version of the milling centre, CEREC inLab® MC XL (see Figure 3), is capable of milling a crown in as little as 4 minutes. CEREC® systems may be described as measurement devices that operate according to the basic principles of confocal microscopy (3, 4) and according to the active triangulation technique (3, 5 and 6). A camera projects a changing pattern of blue light onto the object (see Figure 4) using projection grids that have a transmittance random distribution and which are formed by sub regions containing transparent and opaque structures (7). Moreover, by means of elements for varying the length of the optical path it is possible, for each acquired profile, to state specific relationship between the characteristic of the light and the optical distance of the image plane from the imaging optics (3, 4). A light source 3 (see figure 5) produces an illumination beam 7.1, 7.2, 7.3, that is focused onto the surface of the target object 2. An image sensor 6 receives the observation beam 9.1, 9.2, 9.3 reflected by the surface of the target object. A focusing system 5 focuses the observation beam onto the image sensor 6. The light source 3 is split into a plurality of regions 3.1, 3.2, 3.3 that can be independently regulated in terms of light intensity (6). Thus, the intensity of light detected by each sensor element is a direct measure of the distance between the scan head and a corresponding point on the target object (3). As a disadvantage of the system, the triangulation technique requires a uniform reflective surface since different materials (as dentin, amalgam, resins, gums) reflect light differently. It means that it is necessary to coat the teeth with opportune powders before the scanning stage to provide uniformity in the reflectivity of the surfaces to be modelled.

The earlier versions of CEREC® employed an acquisition camera with an infrared laser light source. The latest version employs blue light-emitting diodes (LEDs); the shorter-wavelength intense blue light projected by the blue LEDs allows for greater precision of the output virtual model (see Figure 4). The images are distortion-free, even at the periphery, so that multiple images (e.g. of a complete quadrant) can be stitched together with great accuracy. The CEREC® AC Bluecam boasts an automatic shake detection system which ensures that images are acquired only when the camera is absolutely firm. It is possible to capture a complete half arch in less than a minute. The new CEREC® AC Bluecam offers image stabilization systems. It means that the practitioner does not have to rest the camera wand on a tooth to get a steady focus and the camera automatically captures an image when the wand is motionless, avoiding the need for a pedal button (as the previous model required). Furthermore, it is now possible to scan full arches, while earlier versions of the device made a single image from one perspective. At the end of the scanning stage, the preparation is shown on the monitor and can be viewed from every angle to focus or magnify areas of the preparation. The “die” is virtually cut on the virtual model, and the finish line is delineated by the dentist directly on the image of the die on the monitor screen. Then, a CAD system, called “biogeneric”, provides a proposal of an idealized restoration and the dentist can make adjustments to the proposed design using a number of simple and intuitive on-screen tools. Once the dentist is satisfied with the restoration, he can mount a block of ceramic or composite material of the desired shade in the milling unit and proceeds with fabrication of the physical restoration. During the design stage of the process the use of colour-coded tools to determine the degree of interproximal contact helps to ensure finished restorations that require minimal, if any, adjustments before cementation.

If the dentist has a standalone CEREC AC® system and he can not perform in-office fabrications of restorations, he can forward the digital impression data, using CEREC Connect®, directly to the dental laboratory (1).

ITERO BY CADENT LTD (IL)

The Cadent iTero digital impression system by Cadent LTD, IL (see Figure 6) came into the market in early 2007. iTero system employs a parallel confocal imaging technique (see Figure 7 and 8) (8). As shown in Figure 9, an array of incident red laser light beams 36, passing through a focusing optics 42 and a probing face (Figure 7 and 8), is shone on the teeth. The focusing optics defines one or more focal planes forward the probing face in a position which can be changed by a motor 72.

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