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Digital Impression in Dentistry-A Comprehensive Review

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Abstract

Digital techniques in dentistry offer a fully digital computerized workflow that does not include the standard multiple traditional phases. Digital imprint and computer-aided design/computer-aided manufacturing systems offer a wide range of benefits compared to traditional techniques. The introduction of intraoral scanners has radically changed the way in which the dentists approach the restorative workflow. The constant evolution of the hardware and software in relation to this has made a digital end-to-end restorative solutions a reality. Precision, accuracy, and hassle-free procedures have made these systems user-friendly and patient-friendly. There are many advantages in using this advanced technology.

Keywords: CEREC digital, Computer-aided design/computer-aided, Impression

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Introduction

The most critical step in the process of fabricating precisely fitting fixed or removable dental prostheses is the capture of an accurate impression of prepared or unprepared teeth, dental implants, edentulous ridges, or intraoral landmarks or defects.[1] They help in diagnosis, treatment planning, and fabrication of restorations.[2] The advent of highly innovative and accurate impression systems based on new technologies has created a paradigm shift in the concept of impression making.[1] The advancement in the field of computer technology and the development of computer-aided design/computer-aided manufacture (CAD/CAM) in the engineering field helped us to develop CAD/CAM for dental use.[3] Digital intraoral imaging represents an innovative method that enables the dentist to construct a virtual computer-generated copy of the hard and soft tissues with the use of lasers and other optical scanning machines.[4] The digital method of making impressions has great accuracy and will for sure reduce the necessity for traditional impression methods in the near future. The data is stored in specific software for further fabrication of restorations or positive replica or any other appliance manufacturing. This also allows the retrieval of data at any given point of time for further analysis and follow-ups.[2,5] This article will discuss the various aspects of digital dental impressions.

From Bites to Bytes: A Brief History of Impression Making in Dentistry

Impression making for restorative dentistry is a relatively recent concept in the millennia-old history of restorative dentistry. It was not until 1856 that documentation exists of the use of an impression material other than beeswax or plaster of Paris when Dr. Charles Stent perfected gutta percha for use in the fabrication of the device that bears his name for the correction of oral deformities.[6]

The polysulfide rubber impression material introduced in the late 1950s originally developed to seal gaps between sectional concrete structures overcame some of the problems of the hydrocolloids.[7] The introduction in 1965 of the polyether material Impregum by ESPE, GmbH as the first elastomeric impression material specifically developed for use in dentistry afforded the profession a material with relatively fast setting time, excellent flow, outstanding detail reproduction, adequate tear strength, high hydrophilicity, and low shrinkage.[8] Condensation silicone impression materials subsequently were developed, but these also suffered from problems with dimensional accuracy. The creation of addition silicone vinyl polysiloxane impression materials solved the issues of dimensional inaccuracy, poor taste and odor, and high modulus of elasticity, and offered excellent tear strength, superior flow, and lack of distortion even if models were not poured quickly.[9]

In addition to the many problems inherent in the accuracy of the elastomeric materials themselves, further distortions can occur by mistakes made in the mixing of the materials or in the impression-making technique, the use of non-rigid impression trays, and the transfer of the impression to the dental laboratory, the need for humidity control in the dental laboratory to assure accuracy in the setting of the gypsum model materials, etc. Newer technologies that allow for the use of digital scanners for impression making are indeed a welcome development.[10] Three-dimensional (3D) digitizing scanners have been in use in dentistry for more than 20 years and continue to be developed and improved for obtaining virtual impressions. The CAD/CAM dental systems that are currently available are able to feed data obtained from accurate digital scans of teeth directly into milling systems capable of carving restorations out of ceramic or composite resin blocks without the need for a physical replica of the prepared, adjacent, and opposing teeth.[1]

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Advantages of Conventional Impressions[11]

1. The technique is well known and acceptable
2. Simple equipment needed
3. Cost ranges from low-to-moderate
4. Known accuracy
5. Relatively simple and predictable clinical technique.

Disadvantages of Conventional Impressions[11]

1. Creates mess
2. Discomfort for the patient
3. Air bubbles or debris cause inaccuracies
4. Stocking the materials and trays.

Advantages of Digital Impressions[12]

1. Comparative accuracy with conventional impressions
2. Simpler to use after a period of learning
3. Eliminates the mess
4. Discomfort for patient is reduced
5. Eliminates the need for stocking materials and trays
6. Need for disinfection eliminated
7. No risk of cross infection
8. Easy transfer to laboratory
9. Eliminates the need to articulate the casts
10. Tasks of pouring the impression, making the base, and trimming are eliminated
11. Long-term storage of data.

Disadvantages of Digital Impressions[12]

1. Lack of dentist's familiarity with the concept
2. Complex digital equipment
3. High initial cost of purchase.

Principles Behind 3D Surface Imaging[13]

3D surface scanners are devices that create a digital map of the surface of an object and collect data on its three-dimensional shape and size. The raw data are usually obtained in the form of a point cloud, representing the 3D coordinates of the digitized surface. In practice, there are two main categories of 3D surface scanners: contact and non-contact scanners.

Contact Scanners[13]

Many contact scanners are coordinate measuring machines which are mechanical systems designed to move a measuring probe over a surface and to determine the coordinates of the points comprising the surface. They have four main components:

- The measuring probe: The mechanical measuring probe performs a linear or radial scan of the desired surface and, as it does so, the position of the stylus tip in the x, y, and z planes is sampled at regular intervals. Example of a contact probe scanner in use in dentistry is the Incise system (Renishaw, Wotton-under-Edge, UK), probe has a ceramic shaft on the end of which is a ruby ball
- The control or computing system
- The machine which moves the probe
- Measuring software.

This type of scanner can only usefully be used on hard surfaces such as dental stone, as a soft surface will either deform or wear when in contact with the probe. These scanners are used in the dental laboratory to obtain surface scans of tooth preparations. The 3D information is then used to mill alumina crown copings. Whilst contact probe scanning is very accurate, the scanning process is relatively slow when compared to non-contact optical systems.

Non Contact Optical Scanners

Many 3D laser scanners employ the principle of triangulation to obtain 3D surface images. A laser beam is incident on the surface of the object to be scanned and a camera-like device, such as a charge-coupled device or position-sensitive detector, is used to record the location of the point at which the laser beam strikes the object. Since the positions of both the laser and camera and the angle between them is known, the position of the surface can be calculated using simple triangulation. Laser scans can either be created from a point which is progressively scanned over the object surface, or more rapidly by imaging the object with a series of laser lines or profiles.[13,14]

Photogrammetry also employs the principles of triangulation, but instead of a laser beam, it uses a series of photographs of the object of interest. Variations on this method use aspects of photographic images such as defocus, shading, and scaling which can help give an estimate of 3D shape and depth. The major drawback of this technique is that it is not possible to obtain the dense point clouds required for freeform surface modeling and accurate CAD surface reconstruction. Reconstruction of the acquired image can also be time-consuming.[13]

Interferometric techniques may use laser or white light. Interferometry uses the principle that waves will interact with one another causing interference. If waves are perfectly in phase they reinforce each other, but if they are perfectly out of phase they will cancel each other out. In interferometric shape measurement, light of different wavelengths is projected along a single beam onto a surface. The interference between the wavelengths depends on the distance between the source and the surface, thus fringes of dark and light are formed on the object which relates to the topography of the surface. The advantages of interferometry include high resolution, a long range, and they are also relatively insensitive to mechanical vibrations.[15]

The Structured Light Method uses a well-characterized simple image that is projected onto the surface to be investigated. This image is often an array of black (dark) and white (bright) lines or a checkerboard of black and white squares. Unless the surface is perfectly flat, the image will appear deformed. Once the image is captured a computer algorithm is used to decode the surface topography from the difference between the projected image and the original image.[16] The main advantages of this method of 3D optical scanning are the high speed, low cost, and high accuracy. It is used in the 3dMd facial imaging system.[17] However, the technique is not without its problems as issues such as shading and surface holes or crevices will present problems with image projection and subsequent capture.[13]

The Moir fringe method is another projection technique. Here, light projected onto the surface of interest passes through a grating. The projected image is picked up by a camera after the light has passed back through an identical reference grating. The interference pattern created, in the form of lines on the object surface, can be used to create a 3D surface image.[16]

Digital impression and scanning systems were introduced in dentistry in the mid 1980s. Two types of systems are available on the market today:

1. CAD/CAM Systems
   Example: The CEREC Acquisition Centre (AC) (Sirona Dental Systems) and E4D Dentist™ system (D4D Technologies)
2. Dedicated Three Dimensional Digital Impression Systems
   Example: Lava™ Chairside Oral Scanner C.O.S. (3M ESPE) and the iTero™ system (Cadent).[18]

CAD/CAM Systems

CAD/CAM technology originated in the 1950s with numerically controlled machines feeding numbers on paper tape into controllers wired to motors positioning work on machine tools. The introduction of CAD/CAM concepts into dental applications was the brainchild of Dr. Francois Duret in his thesis written at the Universite Claude Bernard, Faculte d'Odontologie in Lyon, France in 1973, entitled "Empreinte Optique" (Optical Impression).[1]

CEREC

The CEREC 3 system an acronym for Chairside Economical Restoration of Esthetic Ceramics was a bold effort to combine a 3D digital scanner with a milling unit to create dental restorations from commercially available blocks of ceramic material in a single appointment. The CEREC AC system includes the Bluecam-a light-emitting diode (LED) camera that records a series of overlapping single images that the software calculates into a 3-dimensional virtual model of the dentition. The camera records the image data reflected from the surface of the teeth and soft tissues, and a titanium dioxide powder is required to create a uniform reflective surface. The shorter wavelength of the LED blue light has been measured to have a higher resolution compared to that of a red laser liglit. The Bluecam can be used in either a manual or automatic mode. When the camera is used in the automatic mode, it is unable to record data while the camera is moving or shaking. This prevents the capture of blur inaccurate.[19,20]

With this system, the impression process necessitates achieving adequate visualization of the margins of the tooth preparation by proper tissue retraction and hemostasis. Several image views then are made from an occlusal orientation assuring capture of the tooth or teeth being restored, as well as of the adjacent and opposing teeth. Next, the preparation is shown on a touch screen that enables the dentist to view the prepared tooth from every angle and to focus on magnified areas of the preparation. The CAD proposal of an idealized restoration is presented by the system, and the dentist is given the opportunity to make adjustments to the proposed design using a number of simple and intuitive on-screen tools.[1]

E4D Dentist

D4D Technologies LLC (Dallas, TX), an acronym for Dream, Design, Develop, Deliver, introduced the E4D Dentist™ CAD/CAM system in early 2008, after an extended period of beta-testing and fine-tuning to assure a quality product. It consists of a cart containing the design center (computer and monitor) and laser scanner, a separate milling unit, and a job server and router for communication. The scanner, termed the IntraOral red images that would be Digitizer, has a shorter vertical profile than that of the CEREC system, so the patient is not required to open as wide for posterior scans. The E4D Dentist does not require the use of a reflecting agent, such as titanium dioxide powder, to enable the capture of fine detail on the target site.[1]

The E4D Dentist IntraOral Digitizer is a single-image camera that uses a red laser light to record intraoral images. It also works by recording reflected data from the hard and soft tissues. However, it only requires the use of a reflective medium (E4D Accent liquid) when scanning through a thin, transparent area of the cavity preparation.[21] The camera can be used in either a manual image capture mode or automatic image capture mode with Rapid Scan. A series of separate images are recorded from the occlusal, lingual, and facial views for a true 3-D capture. The software provides immediate feedback on each scanned image to ensure all images are accurately scanned.[20] The ICEverything™ (ICE) feature of the system's Denta-Logic software takes actual pictures of the teeth and gingiva before treatment and after tooth preparation, as well as an occlusal registration. The design system of the E4D Dentist is capable of auto detecting and marking the finish line on the preparation. After the dentist approves this landmark, the software uses its Autogenesis™ feature to propose a restoration, chosen from its anatomical libraries, for the tooth to be restored.[2]

Dedicated Impression Scanning Systems

Dedicated 3D digital dental impression scanners eliminate several time-consuming steps in the dental office, including tray selection, dispensing and setting of materials, disinfection, and shipment of impressions to the laboratory. In addition, the laboratory saves time by not having to pour base and pin models, cut and trim dies, or articulate casts. With these systems, the final restorations are produced in the laboratory, but they are fabricated on models created from the data in the digital scans, as opposed to gypsum models made from physical impressions. Patient comfort, treatment acceptance, and education are added benefits. Digital scans can be stored on computer hard drives indefinitely.[1]

iTERO

The iTero™ digital impression system (Cadent, Carlstadt, NJ) was introduced in early 2007, following 5 years of intensive research and beta- testing.[21] The iTero intraoral scanner uses a parallel confocal white light and red laser light camera to record a series of single images to create a 3-D model.[22] The scanner emits a beam of light that is reflected off the tooth surface. Only data reflected back through the filtering device at the correct focal distance is recorded.[23] The scanner captures 100,000 points of laser light and focuses accurately to 300 focal depths spaced 50 μm apart and within one-third of a second, the reflected light is converted into digital data.[1] Although light is reflected from the surface of the tooth to record the data, no reflective powder or coating is required and the camera can be placed in contact with the teeth. The operator is prompted to record a series of scans from the occlusal, facial, lingual, mesio-proximal, and disto-proximal angles of the prepared tooth and additional scans for adjacent teeth. The opposing dentition is scanned separately. The scanned series of images is not continuous, so individual images maybe retaken until adequate data is obtained. A total of 15–30 scanned images maybe required to record the preparation, opposing teeth, and occlusal relationships.[23]

The iTero system includes a computer, monitor, mouse, integrated keyboard, foot pedal, and scanning wand organized on a well-designed mobile cart. Disinfection consists of replacing the disposable sleeve on the handheld scanner. The end of the scanner that enters the mouth has the tallest vertical profile of all the systems, and thus requires wider mouth opening by the patient.[1] Voice prompts guide the dentist in taking a series of scans of the patient's teeth and occlusal registration. The images are captured on the monitor by stepping on the foot pedal. The image on the screen is similar to a viewfinder on a camera, which allows the dentist to position the camera correctly while looking at the screen.

As this is not a continuous scan and no powdering is necessary, the dentist may remove the scanner from the mouth to dry or rinse fluids as necessary.[24] Individual images may be retaken to ensure capture of adequate detail. If the preparation must be modified, the quadrant needs to be rescanned after all adjustments are complete.[25] After all scans (at least 21) are completed, the dentist steps on the foot pedal, and within a few minutes, the digital model is displayed on the monitor. Using a wireless mouse, the dentist can rotate the model on the screen to confirm that the preparations are satisfactory before temporizing the teeth and sending the scans to the laboratory. All patient data and laboratory prescriptions are input into the computer before the scanning procedure. Digital data are sent wirelessly to Cadent, where the digital impression refined and a hard plastic model is milled. Cadent then returns the model to the local dental laboratory, which completes the final restoration.[26]

LAVA C.O.S.

The Lava™ Chairside Oral Scanner (C.O.S.) was born out of the research of Professor Doug Hart and Dr. János Rohály at the Massachusetts Institute of Technology. The Lava C.O.S. was created at Brontes Technologies Inc (Lexington, MA) and was acquired by 3M ESPE (St. Paul, MN) in October 2006. The product was launched officially at the Chicago Midwinter Meeting in February 2008. The method used for capturing 3D impressions involves active wavefront sampling (AWS), which enables a 3D-in-Motion technique. This technique incorporates revolutionary optical design, image processing algorithms, and real-time model reconstruction to capture 3D data in a video sequence and model the data in real time. Other digital impression scanners use triangulation and laser approaches, which rely on the warping of a laser or light pattern on an object to obtain 3D data. In so doing, these methods are relatively slow and have the downside of distortion and optical illusion. AWS scans images quickly (approximately twenty 3D data sets per second, or close to 2,400 data sets per arch) in video mode and creates a highly accurate virtual on-screen model instantaneously. Three sensors record the clinical situation from varying perspectives and use proprietary image processing algorithms to process the model.[27]

The Lava C.O.S. unit consists of a mobile cart containing a computer, a touch screen monitor, and a scanning wand, which has a 13.2-mm wide tip and weighs 14 oz (about the size of a large power toothbrush). The end of the scanner that enters the mouth is the smallest of all the systems. The camera at the tip of the wand contains 192 LEDs and 22 lenses. There is no need for a keyboard or mouse, as the monitor displays a keyboard for all data input. Disinfection involves a simple wipe down of the monitor with an intermediate level surface disinfectant designed for use on nonporous surfaces and replacement of the plastic sheath on the wand. The Lava C.O.S. requires only enough powdering to allow the scanner to locate reference points. Therefore a very light dusting of powder is required and is produced using the powdering gun provided with the unit. Following preparation of the tooth and gingival retraction (if necessary), the entire arch is dried thoroughly and lightly dusted with powder.[1]

The operator has a field of view of approximately 10 mm × 13.5 mm, and the camera must stay a working distance of between 5 mm and 15 mm from the surface being recorded; otherwise, a fail-safe component stops capturing data, preventing poor data from being included in the scan. Scan Rewind function allows the user to rewind and delete 10-s portions of the scanned video rather than delete the entire scan.[21]

The dentist begins scanning by pressing either a button on the scanning wand or the start key on the touch screen monitor. A pulsing blue light emanates from the wand head as a black and white video of the teeth appears instantaneously on the monitor. Starting on the occlusal surface of any posterior tooth, the dentist guides the wand forward over the occlusal surfaces of the sextant being scanned and then rotates the wand so that the buccal surfaces are captured. The wand then is moved posteriorly, capturing all the buccal surfaces with some overlap of the occlusal. After he or she reaches the most posterior tooth, the dentist begins scanning the lingual surfaces of all the teeth in the sextant. The "stripe scanning" is completed when the dentist returns to scanning the occlusal of the starting tooth. If any sudden movement occurs, the image automatically pauses and the dentist can continue by returning to any surface that has been previously scanned. The software recognizes data that is already in the computer and resumes scanning without the need for pressing any buttons.[28]

In addition, the Smart scan software can distinguish between surfaces that are intended to be scanned (i.e. teeth and attached gingiva) and extraneous data (i.e. tongue, cheeks, etc). As the teeth are scanned, they turn bright white on the monitor and any areas that remain in red need to be scanned for more detail. To help the dentist maintain the wand at a proper distance from the teeth, a target appears on the monitor to indicate whether the wand is too close or too far away from the teeth. With the help of these on-screen guides, the dentist can modify the continuous scan without pausing, withdrawing the wand, or restarting the scan.[29]

After scanning the preparation and adjacent teeth, the dentist pauses the scan and evaluates the result on the monitor. He or she is able to rotate and magnify the view on the screen, and also switch from the 3D image to a 2D view of the exact images captured by the camera during the scan. A third option allows the dentist to view these images while wearing 3D glasses. After the dentist confirms that all necessary details were captured on the scan of the preparation, a quick scan of the rest of the arch is obtained, which takes approximately 2 minutes.[29]

If there are holes in the scan in areas where data is critical, such as cusp tips or contact points, it is not necessary to redo the entire scan. Rather, the dentist simply scans that specific area and the software patches the hole. After the opposing arch is scanned, the patient is instructed to close into the maximal intercuspal position. The buccal surfaces of the teeth on one side of the mouth are powdered, and a 15-s scan of the occluding teeth is captured. The maxillary and mandibular scans then are digitally articulated on the screen. After all the scans have been reviewed for accuracy, the dentist uses the touch screen monitor to complete an onscreen laboratory prescription. The data are sent wirelessly to the laboratory technician, who then uses customized software to cut the die and mark the margin digitally. 3M ESPE receives the digital file where it is ditched virtually, and the data is articulated seamlessly with the operative, opposing, and bite scans.[20]

At the model manufacturing facility, a stereolithography model is generated and is sent to the laboratory (along with a Lava coping if the restoration is to be a Lava crown), where the technician creates the final restoration. Despite the name of the system, it is not dedicated only to the creation of Lava crowns, as all types of finish lines may be reproduced on the stereolithography dies, allowing for any type of crown to be manufactured by the dental laboratory.[1,20]

Single Image Cameras

The CEREC Bluecam, E4D Intraoral digitizer, and iTero scanner are considered single-image cameras. These cameras capture a series of individual digital images that overlap one another. The overlapping images are "stitched together" by the computer software program to process a single 3-D virtual model. All cameras work in a single line of sight. This means that the camera can only record data that is in the direct line of sight of the camera. Generally, the first image recorded is from an occlusal direction. The data cervical to the height of contour of an unprepared tooth would not be visible to the direct line of sight of the camera. A series of images must be captured as the camera is rotated towards the facial and lingual directions to capture data cervical to the height of contour.[30]

Open and Closed Architecture

All of the computerized systems record the digital impression to a data file in the manufacturer's software program. The initial versions of these proprietary data files were designed with a "closed architecture" concept in that the digital files could only be read and used by equipment from the same manufacturer using the manufacturer's software program. This is still true for the digital files used by the CEREC AC and E4D systems for full-contour chairside restorations.[31]

However, with the advent of digital impression systems, dental laboratories were faced with the potential problem of having to acquire systems from each manufacturer in order to manage all the data files they received from their client doctors. More recently, manufacturers of computerized systems have moved to "open architecture" with their digital files. Multiple corporate partnerships have developed, allowing the use of a specific manufacturer's digital files across a number of different software programs and CAD/CAM equipment. A number of laboratories use laboratory-based CAD/CAM systems such as Dental Wings (Dental Wings, Inc., www.dentalwings.com) or 3Shape System (3Shape A/S, 3Shape Dental Systems, www.3shape.com) to process digital files from every computerized manufacturer available for the dental office.[20]

Concerns with Digital Impressions

A well-accepted principle of restorative dentistry is that the final restoration can be only as accurate and well adapted as the final impression. The clinical challenge is to provide an accurate final impression of the intraoral condition to the laboratory. This concept is equally true for digital impressions. The final restoration can only be as accurate as the recorded data file. All digital impression systems and chairside CAD/CAM systems rely on the ability to accurately record the data file, and there are several principles that are common to all the cameras that significantly influence the outcome.

The first is that digital impressions are as sensitive to moisture contamination as traditional impression materials. Blood and saliva obscure the surface of the tooth or margin from the camera and prevents an accurate recording. At best, the camera records the moisture as an inaccurate surface contour; at worst, no data are recorded where moisture has been collected. In either situation, an accurate restoration cannot be fabricated.[32]

A second principle is that inadequate management and retraction of soft tissues may prevent visualization of the marginal areas, resulting in an inaccurate recording with the camera. As desirable as it may be to scan through soft tissues, this is not possible with current systems. Digital cameras can only record data that is directly visible to the camera lens. Soft-tissue retraction is somewhat different for digital impressions compared to traditional impressions. Traditional impressions generally require that soft tissues be retracted laterally as well as vertically past the tooth preparation margins. The lateral soft-tissue retraction allows for a bulk of impression material at the margin to avoid tearing it upon removal. The vertical soft tissue retraction allows for impressing tooth structure cervical to the margin to ensure the margin is accurately recorded. Digital impressions only require the soft tissues to be retracted sufficiently laterally to visualize the margins. This may be as little as 150 μm to register the margin of the tooth preparation separately from the soft tissues. This is a primary reason diode lasers are particularly popular adjunctive instruments for digital impressions, as they efficiently create lateral retraction while preventing bleeding and ensuring a dry field of view.[1,33]

A common concern relative to the use of digital impression systems is the degree to which they can record subgingival margins. As long as the camera can visualize the margin, it will be recorded. A more critical concern may be how far subgingivally a margin should be recorded. This is especially an issue if an adhesive restoration is being planned for the case, as the outcome of the final restoration is also dependent on the ability to predictably bond the restoration to the tooth, and careful isolation is a requirement for adhesive success.

A general concern expressed by those unfamiliar with digital impression systems is the amount of time it takes to make a digital impression compared to a traditional impression. One obvious factor is that the operator's comfort level while using an intraoral camera significantly impacts the length of time needed to record the images. For those who have never used a wand-type intraoral camera, the initial learning objective is to become comfortable using the camera intraorally while visualizing the image on the computer monitor. A recommended learning technique is to practice scanning volunteer patients without tooth preparations to become comfortable with the camera prior to focusing on scanning tooth preparations.[1,33,34]

Conclusion

Technology is becoming embedded in more and more aspects of clinical dentistry and the ability to capture a digital impression adds a new level of diagnostic ability to the dentist's repertoire. Advances in computer technology now enable cost-effective production of individual pieces. Dental restorations produced with computer assistance have become more common in recent years. Digital dentistry holds much promise for the future, the challenge for the growing list of players is to ensure that the technology delivers true benefits to practitioners and patients in terms of clinical outcomes regardless of the "beauty" of the process involved while at the same time ensuring that affordability is maintained and investments can well and truly be returned.

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