Chapter

Optical Impression in Restorative Dentistry

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Abstract

Intraoral scanners are responsible for data acquisition in digital workflow, which represents the first step in restorative dentistry. The present chapter aimed to investigate the various methods for acquiring oral information, diverse clinical applications based on optical impression technique, use of intraoral scan data according to the need for model, and the various considerations regarding the selection of intraoral scanners suitable for clinical goals. The acquired optical impression data can be sent anywhere in the world, which offers the advantage of overcoming any temporal or spatial constraints. The purpose of this chapter is to understand digital workflow using optical impression and to learn how to use it effectively in clinical practice.

Keywords: optical impression, intraoral scanner, digital workflow, CAD-CAM, digital dentistry

1. Introduction

Since its first application in restorative dentistry by Francois Duret in 1973, computer-aided design/computer-aided manufacture (CAD/CAM) has become engrained in dental practice. The workflow of the manufacturing of prostheses via digital restorative dentistry can be divided into three steps: image acquisition, in which the structure inside the oral cavity is documented; CAD, the acquired images are imported to a computer program to design the desired restoration; and CAM, the restoration is manufactured from the desired material based on the design data. In the image acquisition stage, an intraoral scanner may be used to scan the oral cavity, or a stone model can be scanned after impression making and stone pouring procedure. In the CAD step, different software (S/W) modules can be used to design various types of prostheses, such as a crown, removable partial denture, complete denture, and implant surgical guide. The methods used in the CAM step include computerized numerical control (CNC) milling and 3D printing, which is also called as rapid prototyping or additive manufacturing. The milling process can be further split into the tool-path-calculation and milling processes; the former converts the path that the milling drill must pass through into numeric values to inform the latter process, the three-dimensional subtractive production of the designed prosthesis. 3D printing can be divided into the support positioning and slicing processes; the former entails the formation of supports to hold the designed prosthesis from below, while the latter refers to the actual printing of the designed prosthesis.

Dental CAD/CAM systems are categorized according to how data is acquired and whether the restoration can be fabricated within the dental office on the same day.
Hence, such the systems can be divided into in-office or in-lab systems, the former of which is further distinguished according to whether the dental office is equipped with a milling machine. The material used in an in-office system is relatively expensive because it uses a Mandrill type, which is used in small milling machines and manufactured exclusively for dental application; moreover, the material is also limited to manufacturing inlays and single crowns. However, it offers the advantage of being an all-in-one system that allows the finished product to be obtained within the dental office. An in-lab system involves transferring the data scanned from the patient to a laboratory equipped with the capacity to manufacture a range of prostheses. With traditional LAVA and Procera systems, the laboratory can produce zirconia crowns by scanning a plaster model with a desktop scanner; or the plaster modeling process can be precluded by directly acquiring a digital impression with an intraoral scanner, which further shortens the time required for the model preparation and allows the manufacture of the prosthesis to be completed at any laboratory in the world.

The intraoral scanner was originally invented by Mörmann and Brandestini, and was first applied to patient care in 1985. The technology was confronted by the difficulty of accurately scanning a wide area: the intraoral scanner was limited by the size of the optical window of its scanner tip; spatial data of the oral cavity consequently needed to be aggregated to complete an image of the entire area. Recent advances in optical systems and image processing S/W have led to the gradual expansion of their applicability. Indications that were limited to just inlays or single crowns are now being used in larger cases, including longer fixed dental prostheses and implant prostheses, as well as various intraoral devices, such as implant surgical guides, individual trays for dentures, and metal frameworks of removable partial dentures. Accordingly, this chapter will examine the current state of using intraoral scanners in restorative dentistry for optical impressions and considerations when assessing the performance of intraoral scanners.

2. Classification of methods for acquiring oral information

2.1 The inception of intraoral scanning, in-office systems

The in-office system has a lengthy history that spans over 30 years since the introduction of CEREC in 1987. It now allows for the same-day manufacture and installation of dental restorations using a small dental milling machine. This system is also referred to as an all-in-one system since it is equipped with an intraoral scanner for image acquisition, CAD and tool-path calculation S/W for restoration design, and milling machine. Dentsply Sirona is the supplier of CEREC-branded products, and together with monochrome photography-based Bluecam, color video-based Omnicam, and the low-cost APOLLO Di, it offers various systems according to the different grades of intraoral scanners. In addition, the E4D dentist system that partially includes CEREC technology has continued to evolve, and now Planmeca supplies this intraoral scanner system called PlanScan. Carestream has introduced photography-based CS3500 and video-based CS3600 intraoral scanner systems. On account of being all-in-one systems, many are closed architecture systems with a limited ability to export scanned data for use in other S/W; however, there is a growing trend favoring open architecture systems.

2.2 Popularization of digital-age, in-lab systems

CAD/CAM systems already feature a broad range of applications in dentistry, even without the added benefits of an intraoral scanner. The CNC milling process
that allows for enlarged manufacture at the same magnification to overcome the properties of zirconia by showing change in volume during sintering is an outcome that has long since been integrated into dental practice. Desktop scanners used in laboratories to scan plaster models use a traditional method based on the principle of active triangulation; as a result, the image acquisition unit is fixed on the upper part of the scanner. It is consequentially difficult for the scanner to register areas where undercuts may occur, such as the sub-marginal area and proximal surface of the abutment teeth, which require die work to separate the abutment teeth after producing the plaster model (Figure 1). To ease the time constraints associated with pouring the plaster and separating the dies, attempts have been made to directly scan the impression without pouring plaster over the impression or acquiring data directly from the impression taken with a plastic tray by using a cone beam CT scanner, which is installed in most dental offices today. Difficulties with scanning thin, long teeth with impression scanning technique and low data-resolution images acquired by CT scanning still remain to be addressed. The latest trend in desktop scanners have evinced progress towards making scanning more convenient and efficient, and there is a change towards creating open designs that lack a door by using light sources with shorter wavelengths.

2.3 Advances in intraoral scanners, open architecture intraoral scan systems

Ever since intraoral scanners became readily available in dentistry, they have played a role in the first step of workflow for the fabrication of prostheses. The acquired data can be sent instantaneously anywhere in the world, which offers the advantage of overcoming any temporal or spatial constraints. Because an intraoral scanner must acquire data from a limited space by imaging small structures in the oral cavity with many undercuts, it is based on a principle different than that which informs desktop scanners, which fix the image acquisition unit to the upper

Figure 1.
Model scanning process through the desktop scanner. Because of the undercut area, an abutment scan is required separately. It is necessary to perform the die trimming process of the stone model.
part of the scanner and use proprietary technology patented by the company that manufactured the scanner. The CEREC system featured a “closed system” in which all workflow takes place within the in-house system. After the introduction of iTero scanners (Align Technology Inc.) in 2006, which are based on an “open system” that acquires scanned data usable in various S/W, intraoral scanner became increasingly popular among clinical dentistry practices.

The operating principles behind intraoral scanners include the active triangulation used mostly in the CEREC system and confocal microscopy chosen by iTero and Trios (3Shape) systems. The operating methods of intraoral scanners can be divided into image-stitching and video-sequencing methods. Intraoral scanners underwent rapid advances in hardware since the mid-2000s, which included various advances in anti-fog heating devices, color scanning, portable design, and video imaging methods. Advances in S/W have followed suit, including improvements in the stitching of scanned data and upgrades in intuitive scan S/W interfaces. Recently introduced intraoral scanners reflect endless improvements in their convenience and efficiency in actual clinical practice by making them smaller, wireless, light-weight, and cost-effective, as well as supporting database through cloud computing. Further, the availability of intraoral scanners has risen sharply owing to the reduction in patient discomfort and increased clinical efficiency of dentists.

3. Various clinical applications through obtaining optical impression

We have examined various scanning systems in restorative dentistry that apply CAD/CAM technology. Here, we will examine how digital technology is actually being used and applied based on actual clinical cases.

3.1 Use in diagnostic fields

When the 3D positional relationships between teeth need to be determined for diagnosis and treatment planning in cases with poor occlusal relationship between upper and lower teeth, it is common to perform alginate impression taking, followed by the analysis of the diagnostic model mounted on the articulator. In particular, much information can be gained from the contact relation during lateral movement and relationship of the upper and lower molars from the distal-to-mesial direction that cannot be seen inside the oral cavity, a considerable amount of preparation time is required to build the plaster model and mount it, which makes it impossible to see the outcome on the same day the patient was admitted. However, using an intraoral scanner to obtain a digital impression of the region of interest allows the data to be used immediately for diagnosis without the delay required for plaster setting time. An oral examination was performed on a patient who was admitted to the department of prosthodontics after placement of three implants in the left upper molar region. The patient showed poor occlusion due to a buccally collapsed upper second molar, which is the antagonist tooth. In this case, it was difficult to decide whether to fabricate the implant restoration as is or to do so after restoring the occlusal relationship first by performing a root canal treatment on the collapsed opponent tooth and covering it with a single crown. By taking an optical impression on the day of diagnosis and importing it into CAD software, the superstructure was designed on top of the implant and the occlusal relationship with the opponent tooth could be assessed from the distal direction. This was helpful in determining the treatment plan during patient consultation on the day of the visit and the patient was highly satisfied after implant prosthesis was installed (Figure 2).
3.2 Use in fixed dental prosthesis

For esthetic restoration performed by acquiring data on anterior teeth via intraoral scanning, crowns may be fabricated via a direct wax-up of the cast to reproduce the 3D characteristics of teeth surface. The crown fabrication and installation involves 3D printing of a model based on data from intraoral scanning, wax-up on the die, investment and burn-out, and pressing of the esthetic material.

A male patient in his 20s was admitted for restoration of two upper central incisors at a stage when he was about to complete his orthodontic treatment. Because the orthodontic bracket remained on the labial surface of his anterior teeth, the impression body could not be removed once the impression material hardened with the traditional impression method using silicon impression material; blocking out the bottom portion of the bracket with utility wax would not allow the shape in that area to appear on the impression body. Accordingly, instead of using such method, digital impression was taken using intraoral scanner (Trios, 3shape). After designing the rapid prototype in a model builder program, the model was obtained by 3D printing. After assuring the esthetic surface texture of the anterior teeth via wax-up on the printed die, it was fabricated by investment and pressing with lithium disilicate (eMax, Ivoclar) (Figure 3).

A female patient in her 30s visited the clinic for fabrication of a 5-unit fixed dental prosthesis. The patient was pleased with the shape of the provisional teeth and its shape was replicated for permanent restoration. The optical impression was obtained for abutment and provisional restoration and the restoration was designed by the “double scan” technique. While referencing the relationship between the opponent and adjacent teeth on the 3D printed model, porcelain was built on top of the zirconia coping to complete the final restoration (Figure 4).
3.3 Removable partial denture metal framework, more intuitive design

Because an intraoral scanner is a device that reproduces a 3D structure based on images, functional impression that selectively presses the tissues or border molding that physically takes an impression of the maximum vestibular depth without impeding the movement of the cheeks and tongue by moving the neighboring muscles is impossible. Moreover, because an edentulous arch does not have 3D features, continuously stitching small images determined by the size of the scanner tip can introduce multiple errors and the tissue surface being shiny makes it even more difficult. Therefore, instead of using an intraoral scanner, a desktop scanner obtaining image of master cast made from a traditional functional impression is recommended for cases of removable dentures.

Concerning a 74-year-old male patient who wanted a mandibular partial denture, zirconia surveyed restoration fabricated by milling based on a design that considered the path of insertion and removal of the denture in CAD S/W after digital intraoral scanning (iTero, Aligntech) was installed into the oral cavity of the patient. Subsequently, a master cast was obtained by functional impression taking, which was scanned and the design S/W, exclusive for partial dentures (Freeform, SensAble), was used for electronic surveying to determine the optimal path of insertion and removal by adjusting the inclination of the cast in consideration of the amount of undercut in the entire arch in a virtual space. To design the metal structure, the area that would be covered with the denture base was determined and the finish line was set after forming a lingual bar major connector. A rest was designed and a butt-joint was added. After designing the lattice-structure of the minor connector that joins the denture base to the major connector, a retentive arm determined via electronic surveying was added to the undercut area of the retentive
Figure 4.
The outer appearance of the provisional restoration that the patient had become accustomed to from prolonged use after extraction was replicated via a double scan technique after optical impression.

Figure 5.
A surveyed restoration was fabricated according to the path of insertion and removal of denture shown on data obtained from intraoral scanning. After using burn-out resin to print the framework structure designed by electronic surveying, the partial denture was fabricated by investment casting.
tip to complete the framework design. After reviewing the overall design, sprues for the metal casting were also designed. Plastic material that could be burned out was used for 3D printing to invest and cast the metal structure, after which the denture was completed by a traditional denture curing process for installation (Figure 5). The function of the retentive arm operated clearly during denture installation and removal due to electronic surveying. This system uses a unique input tool called a haptic interface. Once the mouse arrow touched the polygon wall, the arrow could not move any farther inward through a forced feedback effect, whereby the 3D shape of the teeth model could be formed with tactile feedback.

3.4 Use in complete denture cases

For the digital complete denture, a model scanning is mainly performed. Several companies have introduced systems that shorten patient visits by integrating treatment steps. Denture base resin materials must prevent discoloration and contamination while functioning inside the oral cavity for an extended period. Therefore, the materials must have particles that are smooth and densely packed. Heat-curing resin has therefore been used as the material for a complete and partial denture base. To withstand the packing pressure of resin, a frame with plaster material and metal flask are made. Subsequently, the complete curing of resin is induced by boiling it in a water tank. In the digital process, the denture profile can be milled or 3D printed after CAD design. Companies that manufacture and supply digital complete dentures use their own proprietary methods to overcome these limitations, including the use of hard resin with densely packed particles, milling a resin disk block

Figure 6.
The individual tray was designed and 3D printed on the edentulous data obtained by the intrasoral scanner, and the functional impression was made. The complete denture module was used to design the shape of the tooth array and the denture base. The denture base was machined with a milling machine, and then the artificial teeth which are the same as the library were bonded on it.
that is larger than the complete denture being fabricated. Another attempt involves 3D printing the flask itself, which functions as a negative mold of the denture base through the traditional packing and curing process. After designing the denture, a try-in denture may be provided to check whether the denture fits the lips and facial shape of the patient. Moreover, to improve communication between the dentist and lab technician with regard to denture design, webpages are available with interfaces allowing the dentist to check and freely modify the design once the alignment of the prosthetic has been completed (Figure 6).

3.5 Various applications in implant cases

When fabricating a computer-guided implant surgical template, guides with replication of radiographic template tissue surface obtained from CT data have poor internal adaptation due to limitations in the resolution on CBCT, which can lead to poor stability during the surgery and diminish the accuracy of implant placement. These deficiencies can be improved by matching the cast scan or intraoral scan data with CT results. A 52-year-old male patient visited the clinic, wanting three implants in his lower right molar region. The implant placement was planned by matching the data obtained from iTero intraoral scanner and CBCT. A surgical guide was fabricated using a 3D printed wax model. Because the fabrication used high-resolution data, the guide functioned stably during the procedure, despite the fact that it was a dentulous case that did not use a separate fixing pin. After implant healing, the digital intraoral impression was made and the customized abutment and superstructure were fabricated (Figure 7).

Figure 7.
The CBCT and intraoral digital impression data were matched to establish an implant plan that avoided the inferior alveolar nerve. A computer-guided implant surgical template was made on the 3D-printed model to assist the surgery. Digital impression taken after healing was used to fabricate the customized abutment and superstructure.
The digital workflow for fabricating implant prosthesis is easier than fabricating restoration for natural teeth. For the latter, the crown margin must be scanned precisely, whereas with implants, after connecting a digital impression coping or scan body on the implant, only the shape of the scan body needs to be accurately captured; the margin between the abutment and superstructure is accurately aligned by the computer. When forming an occlusal relationship in the implant case, the implant restoration should be fabricated to minimize interference in lateral movement. A digital impression (Trios) was obtained for the fabrication of an implant superstructure in a 56-year-old male patient with overdeveloped masseter muscles. To ensure the patient was guided to centric occlusion when taking an optical impression of the buccal bite, the scan was performed with the occlusal point marked by articulating paper. Because a color intraoral scanner was used, the occlusal point appeared on the occlusal surface in a colored display mode. By comparing the pattern of occlusal point distribution and the markings of the distance of the computer-generated occlusal alignment by buccal bite, it was determined that both data indicated the same occlusal points; otherwise, the positional adjustment handle could have been used to finely adjust the relation between the maxilla and mandible. The articulator function can be used by aligning the maxilla and mandible on the occlusal plane of a virtual articulator. In the present case, group-function occlusion with a large premolar cusp inclination was identified and the area with early contact by implant prosthesis during eccentric movement was adjusted in the CAD software to allow fabrication of prosthesis with minimal lateral pressure (Figure 8).

Figure 8.
The color function of the digital intraoral scanner was used to compare the marked occlusal points and computer-generated occlusal alignment in testing the accuracy of occlusal registration. A virtual articulator was used to adjust the cusp angle in a patient with an overdeveloped masseter muscle to ensure that excessive lateral force was not exerted on the implant.
4. Use of digital impression data, classified according to the need for modeling

When a digital impression is obtained via an intraoral scanner, the outcome is 3D data consisting of a set of triangles or polygons, which are the smallest units that form a plane. The data are imported to dental CAD S/W to design the prosthesis and the final product is obtained through the CAM process, but because the scanned data cannot be physically handled, consideration should be given as to whether a separate model should be built for any additional work. Producing a working model of the digital impression usually involves CNC milling or 3D printing.

The methods for using the digital impression data from an intraoral scanner can be divided into three types depending on whether production of a model is needed (Figure 9). First is the model-free production method, in which only the prosthesis is fabricated and the process of model production is omitted; this is employed when only a small area is being restored. Second is the method by which a model is built to complete the final form of the prosthesis or for fitting. As the reference for porcelain firing, a model may be used to test the fit of a prosthesis against opposing and adjacent teeth. The last method is the active use of a separately built model. It is used in cases for direct wax-up to reproduce the fine details of the 3D characteristics of anterior teeth surfaces. The prosthesis would be fabricated by the traditional method of direct wax-up on the die of the model built by milling or 3D printing.

4.1 Model-free workflow

With the gradual expansion of the clinical application of monolithic zirconia or full-contour zirconia crown without the build-up of feldspathic porcelain, the clinical technique of model-free prosthesis fabrication using an intraoral scanner

![Figure 9. Methods for using a digital impression data from an intraoral scanner according to the need for modeling.](image-url)
has gained broader use (Figure 10). Formerly, the lack of knowledge concerning coloration techniques and shallow penetration of coloring material resulted in unsatisfactory esthetic outcomes due to the opaque-white color of zirconia appearing after occlusal adjustment. However, as a result of deeper color penetration and the introduction of more transparent, naturalistic zirconia blocks, this problem has practically disappeared.

There are differences in tooth preparation design depending on the clinician, especially axial-wall taper and rounding of the abutment teeth edges. Therefore, when starting the model-free clinical process for the first time, it is necessary to adjust the values of the parameters for the inner surface of zirconia crown inputted into the prosthesis design S/W to match the teeth preparation tendencies of the clinician. When the internal gap of restorations fabricated by inputting several different CAD parameters were measured, the restorations fabricated by means of the model-free workflow exhibited a marginal gap that was slightly higher than 100 microns, which would be within the clinically allowable range as reported by McLean et al. The line angle and occlusal surface showed large internal gaps, just like zirconia crowns fabricated by in-lab process using a model scanner. In addition, the margins of the zirconia crowns fabricated via the model-free workflow showed a slightly over-contoured tendency as compared to the conventional emergence profile. In such a case, plaque retention below the margin occurs more readily and the likelihood of gingival inflammation increases as well. The reasons for over-contouring in the margins of the crown are as follows: Because the thin portion of the zirconia crown margin may break off during fabrication if the amount of abutment tooth preparation is insufficient, the crown is milled to leave enough thickness so that the thickness can be adjusted manually relative to the die of the stone cast. However, in the model-free concept, the work is based on intraoral scan data. The traditional silicon impression material can express the contour of the tooth root on the stone die to a certain degree by penetrating up to 5 mm below the margin of the abutment tooth; whereas the intraoral-scanner method is based on an imaging technique, and the undercut below the margin does not scan very well. Therefore, there is no root contour that can be referenced during the CAD process, and the root

Figure 10.  
Case of fabrication of prosthesis based on model-free concept.
contour is insufficiently reproduced in the die milled/printed, limiting the ability to refine the marginal area of the zirconia crown that was fabricated with extra thickness. In other words, the root contour below the margin of the impression body must be registered to a certain degree to allow for a prosthetic design with a naturalistic emergence profile; however, the digital impression taken with an intraoral scanner does not register enough of the area below the margin when compared with the traditional silicon impression. Therefore, when using a model-free workflow with an intraoral scanner, clinicians need to consider these points and reaching an understanding with the laboratory.

4.2 Cases when a model is needed

The cases that require a physical model are those that require additional finishing work after the fabrication of coping. In such cases, the intraoral scan data may be sent separately to the model production center. Both CNC milling and rapid prototyping can be applied to model production. The milling process uses a polyurethane block with wear resistance against subsequent wax-up work, while rapid prototyping by 3D printing also uses comparable resin as the material. As 3D printers have become readily available for in-office use and are supplied with model building materials, many dental offices are starting to print models in the office.

Model production requires the scanned data to be processed. An example using Model builder (3shape, Denmark) S/W is as follows (Figure 11). First, any area unrelated to the area being restored or the movable tissue away from the alveolar bone are deleted to reduce the overall size of and optimize the data. By setting the position of the scanned dental arch to match the occlusal plane of the virtual articulator and checking the occlusal relationship automatically aligned by the lateral bite scan acquired together with the upper and lower jaw scan, the position of the
upper and lower jaw is carefully revised on CAD when necessary. After setting the margin line of abutment teeth to separate the die portion from the other parts of the model, the path of insertion and removal is determined to match the direction of adjacent teeth. After aligning the finished model to appear in the center of the simple articulator, sending data to a 3D printer or milling machine for output can yield the shape of the simple articulator, while also reproducing the occlusion that the patient had at the time of intraoral scanning by physically holding the upper and lower jaw models in hand. Although limited in scope, such model building S/W helps to inform the revision of data, which can be used to modify the impression of the abutment teeth in the marginal area that may not have been acquired well. Such work may be performed in cases where the patient cannot return to the dental office and the prosthesis must be fabricated immediately. Data are not perfect immediately after the acquisition of digital impression with an intraoral scanner, and the data must therefore be reviewed before the patient returns to home to make sure that important parts, including the margins, have been imaged properly.

Models built by milling or printing are usually used in cases of porcelain fused to zirconia restoration. It is also used in implant restoration cases where the implant prosthesis is generally fabricated as an abutment-superstructure dual structure. If pretreatment is needed to check a model due to the range of the prosthesis being too large, a model can be built separately and used accordingly.

4.3 Use of traditional methods

In addition to the indirect purpose of using a model to check the fit of prostheses fabricated by CAD/CAM process, it can be used for wax-up on top of a die model.
The reason for its separate categorization is because only the steps from impression taking to model building are performed digitally, while all subsequent processes follow a traditional workflow. Although most of the processes in restorative dentistry are performed digitally, there are still limitations in expressing the fine surface texture of the anterior teeth by milling or printing, and materials used for milling have limitations in expressing various color characteristics. To overcome these deficiencies, the final restoration can be fabricated by a wax-up of the die. If optical impression of the marginal area was properly obtained, a favorable clinical outcome may be expected. However, in cases that require the reproduction of very thin bevels in the margins, such as with gold inlay, it should be avoided: there are limitations to the availability of ultra-high-resolution scanners that can register such fine details of tooth shape or equipment and mill or print fine details at the inlay-bevel level. Moreover, a meta-analysis by Chochlidakis et al. that reviewed the fit of 339 digital and analog restorations reported that digitally fabricated restorations showed a comparable level of marginal fit as restorations fabricated by traditional methods. However, restorations fabricated by the model-free method using intraoral scan data were more accurate than those fabricated on 3D printed or milled model. This is because equipment errors that may occur during the model building process can be disregarded when compared to the model-free workflow; moreover, solutions to this problem can continually be improved as the precision of the equipment advances in the future (Figure 12) [1].

5. Considerations for comparative assessment of intraoral scanners

With the emergence of 3D digital scanners, existing impression acquisition technique is being replaced with digital technology. While intraoral scanners, various CAD S/W, milling machines, and 3D printers are needed to create a digital office, acquiring such expensive equipment can be a burden for private clinics. Therefore, it is prudent for clinicians to obtain various details concerning the accuracy and clinical efficacy of intraoral scanners before investing. The points that dentists should consider when selecting an intraoral scanner can be categorized as shown in the figure (Figure 13). The accuracy of an intraoral scanner can be determined by assessing the following aspects: resolution, accuracy of the range of the quadrant arch, accuracy of the range of the full arch, accuracy of the range of the individual tooth, and accuracy of color reproduction. For hardware characteristics of an intraoral scanner, the following factors can be assessed: scanner-wand size, the need for a scan spray or powder, the maximum depth of field recognized by the scanner, anti-fog function, and durability based on the sterilization of the scanner tip. With respect to clinical efficacy, the following should be considered for actual clinical application: ease-of-operating of the S/W interface; ability to find the scan position or direction during mid-scan; whether the scanned data can be exported to a standard format of an .stl file; the learning curve for assuring the accuracy of data, shortening the scan time, and becoming familiar with the intraoral scanner; and cost-effectiveness of the equipment.

5.1 Accuracy

The most important criterion for an intraoral scanner is accuracy. Currently, the accuracy of intraoral scanners is sufficient in cases limited to a quadrant, but caution should be taken with long restorations that extend beyond the median line. In a questionnaire surveying preferences in digital impression acquisition after using two types of intraoral scanners (image stitching versus video sequencing), the responses were predominantly positive regardless of the type of intraoral scanner.
Such preference was even higher in the age group that was more familiar with digital technology; based on such high preference, it is expected that intraoral scanners will be increasingly implemented and actively used in dentistry [2].

An intraoral scanner collects intraoral images of the patient and recombines the images as a 3D object. While this procedure is being executed, the computer limits the data resolution in the scan S/W. A polygon formed by three points serves as a criterion for assessing the resolution of scanned data. The higher the number of polygons, the higher the resolution. Assessment has been performed by using intraoral scanners to scan the upper central incisor abutment tooth that was prepared for crown. When the polygons that formed the surface of the model were counted, different scanner systems showed variance in the number of polygons to express the same tooth shape (from 6000 to 400,000 polygons). A higher number of polygons is more favorable for expressing sharp lines in the tooth margin. In addition to the number of polygons, the shape of the polygons is also important. Images with uniformly-sized equilateral triangles lead to faster processing speeds during CAD work and a lower probability of errors than do those with many long, needle-like polygons found between more regular planes (Figure 14) [3].

When fabricating a fixed dental prosthesis for natural teeth by using an intraoral scanner, the ability to scan by differentiating the fine gap between the gingiva and abutment tooth margin is an important feature. When gaps ranging in size between 50 and 1000 microns were created and scanned with intraoral scanners, scanners evinced different levels of performance: some were unable to differentiate gaps smaller than 300 microns, whereas others were able to detect 50-micron gaps. Accordingly, it is advantageous to use the latter in clinical practice.

When the jig presented in ISO 12836 was scanned to test the performance of various intraoral scanners, most intraoral scanners, excluding True definition (3 M LAVA), could not scan geometric shapes. Intraoral scanners have a limited optical window size and can perform a scan only when the target object fills more than half of the optical window. Moreover, the algorithm in the system automatically deletes the image when nearby oral tissues, such as the lips or tongue, are included in the scan, which often prevents the intraoral scanners from producing...
normal images of repetitive shapes that can be easily aligned. Accordingly, it may be unreasonable to use ISO 12836 as the testing standard for intraoral scanners.

In addition, trueness and precision should be calculated and considered together when assessing the accuracy of intraoral scanners; when the archer shot all arrows inside the bull’s eye, both the trueness and precision is good; if the arrows are concentrated in other areas, such as the second target, precision may be good, but trueness would be poor; if the arrows are observed in the third target, trueness may be good, but precision would be poor; when the arrows are spread apart, both trueness and precision would be poor.

Crowns, 3-unit fixed dental prostheses, and inlay abutment teeth were fabricated using a commercial high-precision milling machine to assess the intraoral scan data for the unilateral dental arch. Compared to the E4D Dentist and Zfx Intrascan, Fastscan, iTero, and Trios intraoral scanners evinced better accuracy in most cases. Systems that use active triangulation among their scan principles or spray powder showed high accuracy, while there were no statistically significant differences between image stitching and video sequencing methods [4].

When anterior teeth, including canines, are scanned, arch form distortion may occur. Patzelt et al. mentioned widening and narrowing of the molar region, while a clinical trial by Park et al. observed molar distortion and changes in anterior incisal length [5, 6]. Ender and Mehl reported that accuracy may vary according to scanning strategies, while Ahn et al. reported that differences in accuracy were found when the scan direction and order were changed when scanning a complete-arch orthodontic model [7, 8]. For this same reason, intraoral scanner companies specify that the recommended scanning strategy should be used during the whole dentition scan.

Because of the limited optical window size, image recombination errors in the scan S/W of intraoral scanners may occur under certain conditions. When
mandibular anterior teeth with the same size and shape were aligned by varying the interdental gap and scanned using iTero and Trios, both systems detected arch form distortion; the variance where the distortion occurred appeared to be due to differences in the optical system and recombination algorithm of the systems [9].

Park et al. reported on the accuracy of full dentition scan data when a bracket was installed for orthodontic treatment. Each intraoral scanner varied in its ability to reproduce different types of brackets with various materials. In particular, lingual orthodontics with the bracket mounted on the lingual side achieved lower accuracy than did buccal orthodontics; the extent of decrease in accuracy varied among intraoral scanners [10]. Fortunately, there was very little difference in accuracy based on the presence or absence of orthodontic wire. However, even in this, differences in performance among intraoral scanner systems were found [11].

Park et al. reported on the complete-arch scan accuracy of nine different intraoral scanners. A high-precision industrial scanner with an accuracy of <10 microns and over 100,000 scan points was used as the reference in assessing the trueness and precision of intraoral scanners. Various cases of abutment teeth that can be encountered in clinical practice were fabricated precisely with the industrial milling machine to build phantom models that were used in the study. For qualitative assessment on the differences in trueness, comparison of color maps showed that the distortion of the full dentition was not significant in most recently introduced intraoral scanner systems, whereas systems that have been on the market relatively longer showed poorer accuracy; this finding may have been due to differences in the optical system and 3D recombination function of their respective S/W. When the polygon pattern was analyzed at the same position and angle for a more detailed comparison, the results showed that the intraoral structure was differentially expressed. Similar to the deformation of the impression body observed when an impression is obtained using a traditional silicon impression material, such scan errors can also occur in a digital impression body. Therefore, it is recommended that clinicians should consider the possibility of such an error and personally check the important areas in completing the scan. While some intraoral scanner systems were able to accurately reproduce intraoral conditions, other systems were not able to do so. Fortunately, most of the recently introduced systems show clear and accurate results [3].

One of the most common questions concerning the use of an intraoral scanner is how much occlusal adjustment is needed when a crown is fabricated. Although it varies by system, occlusion between the upper and lower jaw is in most cases registered by scanning the buccal bite under maximum intercuspation. For comparative assessment on the accuracy of a buccal bite scan, metal cylinders with various lengths were used to create a space between the teeth on the measurement side, and a buccal bite scan from the opposite side was acquired. Here, occlusal reproducibility of the intraoral scanners was measured by comparing the amount of interdental spacing on the measurement side against the reference scan. The bite was registered higher or lower depending on the system, and the extent of such differences varied. Therefore, when using intraoral scanners in clinical practice, it would be necessary to assess the accuracy of a buccal bite scan [12]. When the buccal bite-scan accuracy was compared in implant cases, the results also showed differences according to the systems used [13]. In addition to such variance in the performance of the intraoral scanners themselves, it should also be kept in mind that the final prosthesis height may become inaccurate if the patient does not bite down with centric occlusion.

Depending on the principle on which the intraoral scanner system is based, the scan distance or depth recognized by the scanner can vary. When the abutment tooth is too long or the gap from adjacent teeth is too narrow, the intraoral scanner must be lowered and rotated to the side to scan that area, since the focal length is limited. In doing so, if the S/W that superimposes the data has poor performance, it
is difficult to obtain an image of the target area with a single scan and the scan time may be prolonged. When six different intraoral scanner systems were used to acquire digital impressions of various inlay cavities with narrow and deep cavities to assess the depth performance of intraoral scanners, the results showed that the pulpal floor depths of the cavities were different than the actual depths. If the cavity is shallow, the fabricated inlay is also thin and gap is filled with cement, which increases the possibility of inlay fracture after long-term use. If the cavity is deep, inlay with high occlusion is fabricated, which requires more time for occlusal adjustment. The bottom surface and lower corners of the inlay cavity box that are difficult to approach with an intraoral scanner on account of their being too close to adjacent teeth show various patterns of scan errors depending on the intraoral scanner system.

Recently introduced intraoral scanners feature polychrome systems that display mapping of natural color texture. Therefore, whether the color information obtained from intraoral scanning can replace the tooth shade selection process when restoring anterior teeth is worth consideration. Color differences in images obtained from digital intraoral scans and clinical photography were compared against a reference obtained from spectrophotometer to investigate clinical applicability. The color shade information obtained from intraoral scan data tended to be slightly bluer than the actual color shade and would thus be problematic to use as absolute data. However, since it is useful as a color map of teeth with white lines or brown spots, it would be best employed as a supplement [14].

5.2 Hardware

Each intraoral scanner system has its own proprietary operating principle, as each manufacturer has registered patents for the operating principles of its own intraoral scanners; thus, the products are developed to not infringe on existing patents. Moreover, the scanner wands also have different shapes and sizes; recently, there has been a trend towards producing lighter scanners with smaller scanner tips that has led to reduced patient discomfort and shorter scanning times. Indeed, intraoral scanners with scanner tips about the size of a handpiece used for tooth preparation—or even smaller—have been introduced. However, as the size of the optical window becomes smaller, more images need to be stitched together; moreover, because the amount of surrounding structures needed for stitching decreases, the accuracy of the scanned data decreases. S/W development would therefore need to develop in tandem with the decrease in hardware size to use small intraoral scanners with high accuracy that can easily scan the distal surface of most posterior molars in clinical practice.

The need for spray or powder during scanning is another H/W characteristic related to the performance of intraoral scanners. Powder is used to increase the recognition rate of scanners by balancing the reflective conditions of materials with different surface reflectance rates. Nedelcu et al. reported that applying an excessive amount of powder does not have a statistically significantly negative effect on accuracy [15]. However, in actual clinical practice, it is difficult to apply the powder to hard-to-reach areas inside the narrow oral cavity, such as the distal surface of most posterior molars. Moreover, in cases wherein it is difficult to control how much powder is being applied due to the applicator used, an excessive amount of powder may accumulate to cause the scan data to appear differently than the actual condition. In healthy young adults with active saliva secretion, if saliva covers the area where powder was applied, powder may clump together to affect the scan results. Since there are reports indicating that fine and ultrafine particles contained in scanning spray may be harmful to respiratory tract, using powder-free intraoral scanner system is recommended whenever possible. Meanwhile, many manufacturers are
introducing intraoral scanners that do not need scanning spray and can overcome the problem of scattered reflection.

The maximum depth of field recognized by the scanner has a significant influence on the intraoral scanning process. If the range of depth is shorter, systems that terminate the scan if the surface being scanned does not maintain a certain distance from the scanner tip require close attention and are difficult to use, meaning the learning curve becomes very steep. If the scan can be performed without any problem when the scanner tip touches the teeth or even when the distance becomes longer, then the clinical efficacy of such an intraoral scanner would increase.

Because the scanner tip of intraoral scanners consists of a mirror and a glass window, fogging can occur on the optical window when the tip is suddenly inserted into the oral cavity; this can interfere with the scan and slow the scanning speed. To prevent fogging, the scanner tip is heated with a heat wire or air is blown into it. Systems with a heat wire require a waiting time to allow the scanner tip to be sufficiently heated, while systems with airflow can dry the inside of the oral cavity. Lastly, most intraoral scanners feature the ability of changing the scanner tip for sterilization, and thus, durability of the scanner tip based on EO gas or autoclave sterilization must be considered. Small cracks may form on the glass window after 20–30 rounds of sterilization, and images acquired thereafter would contain noise, which may slow the scanning speed and require replacement of the scanner tip.

5.3 Clinical efficacy

With good S/W support, the intraoral scanner system can offer convenience and high efficacy in clinical practice. With respect to such clinical efficacy, ease-of-operation of the graphic user interface (GUI) of the scan S/W itself can be helpful. Input of patient and abutment tooth information must not be unwieldy, and the system must allow all necessary information to be inputted without omission. Further, it must be easy to send the data obtained after completion of scanning to the design center. Recently, many intraoral scanner manufacturers allow for the uploading of data to a cloud server and the notification of the design center. Since scanned data can be viewed in a 3D orientation via a web browser or a separate application, it has become possible to relay work instructions while viewing the data when consulting with the lab technician—not only in the office but also while on the move.

Systems with an excellent S/W recombination algorithm feature a higher clinical efficacy. During digital impression acquisition, additional scans are needed for areas that were not scanned properly. When applying the intraoral scanner to the areas that require additional scanning, and scanning of surrounding area is re-initiated, systems should be able to find the area again quickly and accurately. In particular, when scanning natural tooth abutment, it is effective to scan the mesial and distal surfaces by rotating the intraoral scanner to a 90° angle from the dentition. Systems that reinitiate the scan by automatically recognizing the rotated direction after the scanning is halted are more convenient to use in clinical practice. This is possible if the system has a function that recognizes the change in angle within the algorithm that searches and matches previously scanned data. In addition, intraoral scanners that use video sequencing add data in real-time, and thus, when moving tissues that contact the teeth, the area around the teeth may become messy and contain unwanted data that require deletion from the screen and necessitate the performance of additional scans. To address this issue, systems with an “undo” function that regresses a few seconds to a point prior to the displacement of the tissues being added to the scanned data have been introduced.
Recently, dental CAD S/W with a variety of functions have been introduced; however, whether the operator can export scan data from the intraoral scan system easily as the standard format of .stl is an important point to consider before using them. Many manufacturers of intraoral scanner systems emphasize that their scanners are based on an open architecture. However, there were cases of reduced resolution in which only low-resolution data marred by an unexpected decrease in the number of polygons in the data were exported; inverted surface shell in which the scanned data were converted to an inverted form, rendering them unusable for CAD work; and loss of bite information in which the positional relationships of the maxillary and mandibular data returned to their original points and data on the inter-arch relationship were lost.

Lastly, the learning time required to become familiar with handling the intraoral scanner to shorten the intraoral scanning time and increasing the accuracy of scanned data should be considered. Kim et al. reported the results from an in vivo study that investigated the learning curve for intraoral scanners. A total of 29 volunteers who wished to learn how to use an intraoral scanner participated in 10 sessions of digital impression acquisition lessons over 4 days. Because the volunteers had used an intraoral scanner for the first time, they made several errors, including widening of the posterior arch, lengthening of anterior length, and not combining two or more dental arch fragments together. If the problem could not be resolved by the erase and add scan function, the scan was started again from the beginning. Based on these results, the learning curve was derived. The analysis divided the participants into the groups that used intraoral scanners with image stitching versus video sequencing; both groups showed that adequate learning was achieved after repeated practice. The former achieved a higher learning rate since scanning was difficult, but even after 10 rounds of lessons, scan time was longer than that of the video-sequencing group.

Lim et al. reported on the assessment of changes in data accuracy after repeated practice scanning compete-arch maxillary and mandibular dentition using the two of the same intraoral scanners. In the group that used the difficult image-stitching method, repeated practice influenced the accuracy of scanned data, indicating that practice must be invested to use the method in clinical practice. The group using video sequencing demonstrated a weak learning effect with better accuracy of scanned data relative to the other group. This group was not influenced by clinical experience or the oral structure of the patient, suggesting that video sequencing can be used more easily in clinical practice.

6. Conclusions

Although intraoral scanners have many advantages, there are many unresolved issues with respect to impression acquisition time. Unlike implant cases where the margin between the customized abutment and zirconia crown is arbitrarily set by a computer, impressions cannot be acquired accurately if the margin is not exposed in natural teeth cases. Therefore, the same processes as conventional technique, such as the insertion of a gingival cord and controlling saliva and bleeding, must be performed. Unlike the traditional method of waiting after injecting the impression material, images must be acquired continuously with an intraoral scanner, which necessitates supervision and, hence, more man-hours. As a method for overcoming such limitations, the dentist and dental hygienist must cooperate. Following the insertion of the gingival cord or while the patient is waiting, the dental hygienist can acquire a preliminary scan. Subsequently, the dentist can delete data from the abutment tooth area and perform a precision scan in only that area. By utilizing functions that are only possible by digital method, such limitations can thus be
overcome. In addition, the development of next-generation intraoral scanners that feature the application of ultrasonography and optical coherence tomography is underway. If a digital impression can be acquired easily without having to control bleeding via the gingival cord immediately after tooth preparation, then intraoral scanners will become an essential tool to all dental offices.

Compared to the traditional prosthesis fabrication process, the advantages of intraoral scanners and CAD/CAM include the simplification of the work process; qualitative standardization of the lab process; effective and informed communication between dentist and lab technician; improved work efficiency; and permanent preservation of patient data that can be re-used when necessary. Indeed, there was a case in which a patient for whom we fabricated a partial denture contacted us to tell us that the denture has been lost. This was a case that underwent digital workflow, and the metal framework design was therefore stored in the hospital database. Accordingly, the metal frame was 3D printed and cast to prepare in advance of the patient’s arrival to the hospital. As a result, the denture-fabrication time was halved.

Today, intraoral scanner technology has become more advanced, its interface has become more convenient, and the price of equipment has become more reasonable. As a result, it is becoming increasingly used in dentistry. Because there are many advantages that can be gained should clinical dentistry adopt a digital workflow, there is a bright future for digital dentistry.

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Conflict of interest

None.

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