INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM) dentistry, which is a driving force in the field of digital dentistry, has been making rapid progress. Its products have been added to medical insurance coverage in Japan since April 2014 as “the CAD/CAM resin crown”. The CAD/CAM system consists of the following four components: A 3D digital scanner that converts oral-cavity information into digital data, CAD software that designs restoration models, CAM software that selects the target materials and operates the manufacturing program, and a manufacturing device that builds the designed models into products (Fig. 1).

In the early stages of CAD/CAM applications in the dentistry field, the system designed and manufactured restorations on site from oral-cavity information obtained from a direct photo shoot; however, it did not spread widely because its product was less adaptable than conventional products, manufactured in an analog process using indirect operations. Later, a new stable system was introduced that scanned the operating model based on an optical-impression. The product quality and accuracy were drastically enhanced, and the restoration-product manufacturing process was established as CAD/CAM technology.

Due to the recent movement centered in Europe, to return to basic scanning-technology development, intraoral scanner (IOS) technology has significantly improved. At the International Dental Show (IDS) trade fair in 2015, 20-plus corporations released a new lineup of IOSs. Moreover, recent technological advancements, e.g., the miniaturization and weight reduction of the wand (scanning tip), scanning-speed enhancement, image-resolution enhancement, and imaging-software improvement, have contributed to establishing a so-called model-less restoration process that does not need operating models. A drastic evolution in dental treatment should be anticipated in the future with the clinical application of these advanced IOSs.

INTRAORAL OPTICAL-IMPRESSION

An optical-impression by an IOS involves optically measuring the surface shape of the target teeth or gums directly in the patient’s mouth. IOSs have many advantages, such as reduce patients pain and discomfort, the operator’s burden and the risk on infection, real-time impression scanning and visualization, simple replication and selective scanning, reduction of cost and waste of materials and detection of dental caries and crack. IOSs have become one of the most valuable dental-treatment devices for patients, dentists, dental technicians, and dental hygienists. The IOS accuracy matches or supersedes the accuracy of the conventional-impression and indirect method with working models. IOS is clinically applicable in restoration up to four units. IOS's high reproducibility, information-processing ability, multimedia capability, and simplicity and speed in communication can apply to group examination and identification of disaster victims or dementia patients.

Keywords: Intraoral scanner, CAD/CAM technology, Optical-impression
TYPES OF IOS

Twenty-plus IOS models are commercially available in the world. They are roughly categorized as standalone scanners and all-in-one scanning platforms with CAD/CAM solutions. The former type of scanner processes the intraoral scanning data into 3D models as image files or completes the prosthetic-appliance design using CAD software so the user can forward the data to the dental laboratory (Fig. 3).

The latter type, on the other hand, is the so-called “one-day treatment” device, which is capable of immediately designing prosthetic appliances with the 3D model data from the optical-impression obtained by the IOS. The target prosthetic appliance is completed on the same day with a directly connected manufacturing device that cuts and processes the appliance on site with
the appropriate materials installed (Fig. 4). With proper system construction, a standalone scanner can be an all-in-one scanning platform.

**ADVANTAGES OF IOSs**

Owing to the technological development and improvement of IOSs, which have been used for various applications on a trial-and-error basis, IOSs have become one of the most valuable dental-treatment devices for patients, dentists, dental technicians, and dental hygienists. They have the following advantages.

**Reduce patients’ pain and discomfort**

In the conventional precise-impression process, fluid impression materials, e.g., elastomeric precision-impression materials or agar impression materials, are placed directly in the patient’s mouth and allowed to cure for several minutes. Since the IOS does not need impression materials, it drastically reduces the patients’ discomfort, especially for elders and patients with a strong retching reflex. The scanning operator requires some training; however, with experience, it becomes easy to acquire optical-impressions of the dentitions of both jaws in a few minutes.

**Reduce the operator’s burden**

Precision impression is the most important process in prosthetic-appliance manufacturing, and requires very precise morphology reproduction operations. It is demanding and stressful work for the technicians. One report indicates that the operator’s stress-level decrease and chair-time reduction are evident in the optical-impression using an IOS in comparison with a conventional precision impression.15

**Reduce the risk of infection**

The impression material tray must be sterilized in a conventional precision-impression, and the operators must clean the tray after the modeling materials are removed. Impression material contaminated by various germs in the patient’s mouth can be an infection source in the dental clinic and dental laboratory. Thoroughly addressing these risks is a time-consuming and costly task. The scanning tip of an IOS is autoclavable, and thus, sterilizable. In addition, the 3D images digitally obtained by the optical-impression is transmittable data and do not require the handling of impression materials or conventional models, which are a possible infection source.

**Real-time impression scanning and visualization**

In conventional indirect methods using working models, a precision check of the morphology reproduction, e.g., an abutment tooth, is conducted with plaster models after a precise impression. The optical-impression with an IOS enables its users to confirm the result on the screen as a digital model right after scanning, and to promptly modify the preparation of the abutment tooth as needed.

**Simple replication and selective scanning**

If the obtained digital model contains errors, the entire intraoral scanning process is easily repeatable. In addition, if the obtained impression should be unsatisfactory, the operator can conduct a partial scan targeting the specific areas.

**Image management and archiving**

Unlike conventional plaster models, impressions obtained as digital data with IOSs are manageable with proper media; they do not require space, nor do they deteriorate. They can be easily stored for an extended period as digital files, and users can easily retrieve the data later, at any time and any place, by accessing the files.

**Analysis of abutment tooth formation or restoration**

The IOS enables its users to confirm the abutment tooth formation three-dimensionally on the computer screen, which provides various analysis options, e.g., abutment tooth surface status, opposite tooth clearance, and the shape of margins or undercuts. The user can measure the thickness of the restoration or conduct a morphological and functional structural design of the restorations.

**Reduction of cost and waste of materials**

As impression materials and plasters are no longer necessary, the material cost and waste are reduced.

**Virtual follow-ups**

Digital models enable users to three-dimensionally analyze the chronological changes of a patient’s oral cavity, e.g., tooth-position shift, occlusal wear, abrasion, or gum recession. The initial oral-cavity data is useful as the personal data record of each patient, especially in the case of a substantial tooth defect or loss in the future.

**Tooth and gum color-tone assessment**

Digital models replicate the structural color tone of the tooth or gum-surface formation using a virtual color representation, which the users can utilize in shade-taking or prognosis observation.

**Enable rapid communication**

Digital models can be shared in seconds, as three-dimensional data transmitted through the internet to local and foreign dental clinics, dental laboratories, or milling centers. The relevant data are transmitted through networks, and cloud services can transfer files. This minimizes the time required for plaster-model building and reduces the transportation and delivery costs.

**Merging with maxillofacial data**

Merging intraoral digital models with 3D facial-scan data, jaw-motion data, or 3D image data, e.g., computerized tomography (CT), enables comprehensive examinations and diagnoses. An open-architecture implementation that handles the data in the most commonly used STL file format is also currently in progress.
Table 1 Evaluation criteria of IOSs

| Evaluation ratings           | Additional features     |
|------------------------------|-------------------------|
| Scanning speed               | Touch screen            |
| Scanning flow                | Wireless scanner        |
| Scanning size                | Caries detection        |
| Ease of use                  | CAD integration         |
| Investment cost              | Subscription requirements|
| Accuracy/precision           | Autoclavable tips       |

No temporary restorations
One-day treatments have made obsolete the time-consuming process of building temporary restorations; frequent anesthetization is no longer necessary, and abutment teeth contamination should not occur.

Improved efficiency in the implant treatment plan
Merging intraoral digital data with facial-scan or CT data allows for the smooth and proper planning of an implant treatment.

Detection of dental caries and cracks (Fig. 5)
Cariosity scanning tip uses for caries diagnostics. It helps dentists to detect approximal, occlusal and secondary caries as well as cracks of tooth surface. Caries detection is done with a radiation-free near-infrared light, which is safe for the patient.

IOS LIMITATIONS

Training requirements
Since precise and swift measurements are essential in oral-cavity optical-impression, training is mandatory for IOS operation.

Visualization of a dry operating field
In IOS optical-impression, the scanning device can only measure visually confirmed objects; in other words, the scanning target must be visualized. Since oral fluid can cause a measuring error due to optical refraction, controlling it, especially gingival fluid, is important.

Implant-impression
An optical impression with an IOS requires scan bodies for implants; the software in the implant system and the CAD/CAM system must be compatible. Solutions compatible with various implant systems are currently being released.

Fixed mandibular position
The mandibular position acquired with an IOS is not changeable; it cannot simulate dynamic occlusion at the present. However, some CAD software packages have a virtual articulator that supports jaw-motion parameter adjustment or digital support-pin adjustment.

Scanning fees and closed systems
Some providers store their scanning-data transmissions in cloud-based storage systems, which charge users with fees for optical-impression. Others require additional fees for software updates/upgrades or annual fees. Although most providers’ cloud-storage systems are closed architectures, an open architecture that enables STL data export is currently being implemented.

Cost
Purchasing an IOS is a substantial investment. At present, it is not covered by medical insurance in Japan, and no domestic products are available; thus, it depends on the import of foreign products. Improving the cost-effectiveness by effectively using the 3D image data acquired with an optical-impression is mandatory.

IOS ACCURACY

There are many evaluation criteria of IOSs (Table 1), especially adaptation accuracy is important. Several papers discuss adaptation accuracy in IOS use; most of them compare the adaptability of manufactured crowns. One report found no significant difference in accuracy between crowns manufactured by conventional indirect methods and by model-less IOS operations; 60 to 70 μm near the crown margin, 80 to 90 μm near the center of the axial wall, and 150 to 170 μm at the occlusal surface\(^2\). In other words, most papers report that the IOS accuracy matches or supersedes the accuracy of the conventional-impression and indirect method with working models\(^3,4\).

A research study that directly compared the two-point distance of the scanning data from physical models scanned by a model scanner with that obtained by direct intraoral scanning by IOS showed no significant difference. Moreover, the accuracy of the optical-impression directly obtained by the IOS was closer to the real values\(^5\). However, since a longer scanning distance would degrade the quality in terms of both
precision and accuracy, the report suggests that it is clinically applicable in restorations up to four units, in the current situation. Another study comparing IOS operation procedures reports a minimal deformation in the impression at the distal surface of the dental arch because of an inappropriate method or direction in the scanning operation. A properly operated scan does not show a significant difference statistically and acquires a highly accurate optical- impression of the dental arch.

**EXPANSION OF IOS APPLICATIONS**

Utilizing IOSs leads to safe and efficient dental treatments. In addition, its high reproducibility, information-processing ability, multimedia capability, and simplicity and speed in communication can apply to various situations.

*Storage and utilization of oral-cavity data in group examinations*

Using IOS in dental examinations at schools or enterprises would enable the acquisition of substantial amounts of oral-cavity information, which can be used for epidemiological surveys regarding dental caries or gum status by software analysis. The scanned images can contribute to dental-health guidance as well, by being displayed on screen or in print. Moreover, the IOS scanning data, obtained and stored as personal data when all of the subject’s teeth are replaced with permanent teeth, can be used for observing chronological changes or restoration manufacturing in the event of future tooth damage.

*Identification of disaster victims or dementia patients*

Dental records of remaining teeth or treatments have been regarded as a crucial means for identifying unknown persons, e.g., natural/human disaster victims or wandering dementia patients. Utilizing an IOS contributes to quickly building a personal-information database, and its 3D data-acquisition capability enables swift matching with data obtained on the disaster site.

**CONCLUSION**

Only 5 to 15% of dental institutes in the world have introduced IOS optical-impression®. IOS optical-impressions have many advantages, and their implementation is significant in the realization of safe and secure dental-treatment practices. However, a certain degree of experience and skill are required to operate an IOS at will; its implementation in clinical exercises at medical universities is in immediate demand for use in dental-treatment practices in the future.

As future trends in the IOS market, Transparency Market Research predicted that the market value of 54.4 million US dollars in 2013 would grow to 178.9 million US dollars in 2020, with a 17.1% yearly growth rate. It also predicted that the Asia Pacific region would be the starting point of the growth trend, anticipating an average 20.1% yearly growth rate from 2014 to 2020, and Japan especially would be the largest market in the region. In July 2014, the Japanese Ministry of Health, Labor, and Welfare (MHLW) amended the Pharmaceutical Affairs Law to add “the digital impression device (1803),” as a new class II device. Hence, many proven foreign and domestic IOSs will receive MHLW clearance.

Optical-impressions obtained by IOSs can be applied to purposes other than prosthetic/orthodontic appliance manufacturing, oral-cavity examinations, or explanations to patients. The oral cavity information stored at the time of the patient’s permanent teeth setting, for example, can be used for restoration manufacturing at the time of future tooth damage. In addition, collecting and accumulating data in group examinations, e.g., school medical checkups, would enable the building of big data applicable for various statistical analyses.

The introduction of IOSs into dental treatments in Japan has just begun, and various setbacks have arisen for dentists to cope with, e.g., skeptical attitudes toward the quality of the impression accuracy, significantly expensive initial costs, and psychological resistance toward the paradigm shift in treatment practice from analog to digital dentistry. Various paradigm shifts have been made in the history of dental treatment, e.g., from band crowns to cast crowns, or from chemical-cure composite resins to light-cure composite resins. A new stage of dental treatment, with a digital dentistry revolution driven by IOSs, is arriving.

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