Abstract: Accurate impressions are essential in fabricating dental restorations and fixed dental prostheses. During the last decade, digital impression systems have improved substantially. This review discusses the accuracy of digital impression systems for fabrication of dental restorations and fixed dental prostheses. A literature search in PubMed was performed for the period from July 2010 through June 2017. The search keywords were Cerec, digital impression, direct digitalization, indirect digitalization, and intraoral scanner. Only relevant studies are summarized and discussed in this review. In general, the latest systems have considerably reduced the time required for impression making, and the accuracy and marginal fit of digital impression systems have recently improved. Restorations and fixed dental prostheses fabricated with currently available digital impression systems and intraoral scanners exhibit clinically acceptable ranges of marginal gap in both direct and indirect procedures.

Keywords: digital impression; digitalization; intraoral scanner.

Introduction
Dental computer-aided design/computer-aided manufacturing (CAD/CAM) technology was introduced to prosthodontics in the 1970s. Digital impression systems can utilize intraoral scanners (direct digitalization) or extraoral scanners (indirect digitalization). Indirect digital impression for dental CAD/CAM systems was introduced to dental laboratory work in the 1980s because, at that time, direct digital impressions of abutments required considerable chair time and had limited accuracy. In indirect digitalization, casts are scanned with extraoral scanners. The scanning data are stored digitally and thus can be easily transmitted over the internet if there is any change in the scanning data. Hence, CAD/CAM systems are now clinically practical (1,2).

In direct digitalization, an intraoral scanner acquires data on the dental arches before the use of CAD/CAM technologies. Current digital impression techniques that use intraoral scanners can accurately scan abutments and satisfy the requirements of dental restorations with the use of a computer display, i.e., without fabrication of dental casts. This system has important advantages in reducing impression time, patient burden, and vomiting reflex.

This review discusses recent research on digital
impressions with intraoral scanners for dental restorations and fixed dental prostheses. The included studies evaluated impression accuracy, marginal fit, impression time, dentist and patient assessments of impressions, and clinical outcomes of CAD/CAM-fabricated dental restorations and fixed dental prostheses fabricated after direct and indirect digitalization.

The principles of digital impression systems
Digital impression data transfer systems are classified as open and closed. Open systems handle three-dimensional data for the abutment in stereolithography (STL) format, the format most commonly used in dental CAD/CAM systems. The manufacturer can then easily access the STL data. In closed systems, impression data are used for fabricating restorations and prostheses, in accordance with the limitations of the system. At present, eight intraoral scanner models are used in Japan (Table 1).

Accuracy of digital impressions and conventional techniques
Ender et al. (3-5) evaluated the accuracy of full-arch digital impression techniques and conventional impression techniques. The accuracy of digital impression techniques was lower than that of silicone impression techniques but better than the accuracy of polyether and irreversible hydrocolloid impression techniques. However, another study of intraoral scanners (6) found that digital impression techniques were better than silicone impression techniques in the quadrant range. In other words, accuracy differed in relation to the manufacturer of the intraoral scanner.

In vitro marginal gaps after intraoral and extraoral scanning
The scanning of stone casts from conventional impressions is the standard for dental restorations and fabrication of fixed dental prostheses with indirect digital impression systems. As is the case for other techniques, scanning of a conventional impression and creation of polyurethane casts by fabricating from intraoral scanners milling systems based on the virtual casts are applied.

Studies have compared the marginal gaps of dental restorations and fixed dental prostheses fabricated after intraoral and extraoral scans in vitro (Table 2). Seelbach et al. and Pedroche et al. (7,8) reported good marginal fit in dental restorations produced with the CEREC Bluecam, Lava Chairside Oral Scanner, iTero, and 3Shape TRIOS intraoral scanners. An et al. (9) reported that marginal fit for the iTero was low or similar to that obtained by using polyurethane casts fabricated with a milling system based on virtual casts. Pedroche et al. (8) reported that the marginal fit obtained from intraoral scans was better than that obtained from extraoral scans of polyvinyl siloxane impressions. Ng et al. (10) reported that marginal fit was better than that of a restoration fabricated from lithium-disilicate glass-ceramic ingots by anatomic contour waxing (without cutback) for the lost-wax and/or pressed method by the technician.

Previous studies (11-13) reported that, for fixed dental prostheses, marginal fit with direct digital impressions obtained by using intraoral scanners was equal to or better than that obtained with indirect digital systems. In contrast, Shembesh et al. (14) reported that, as compared with extraoral scanning of stone casts with polyvinyl siloxane impression, marginal fit for intraoral scans was worse for the iTero system and better for the 3M True Definition Scanner. Thus, the results depend on the intraoral scanner used. Keul et al. (11) compared the marginal fit of frameworks fabricated with milling technique after direct digitalization. Marginal fit was better for a Co-Cr framework than for zirconia.
In vivo marginal gaps after intraoral and extraoral scanning

Numerous studies investigated digital impression and conventional impression techniques in vivo (Table 3). Considerable evidence (15-20) indicates that marginal gaps obtained with intraoral scanners are equal to or better than those obtained with extraoral scanners. Ahrberg et al. (17) reported that the marginal fit of fixed dental prostheses was more accurate after direct digitalization than after indirect digitalization.

**Digital impression time**

The time required for impression was compared between direct digitalization and conventional impression in four
studies (Tables 4, 5). A number of studies reported that the total time needed for digital impressions was shorter than that needed for conventional impressions (17,21-23); however, Patzelt et al. (22) reported that the interval required for scanning of the full arch was longer for the Lava Chairside Oral Scanner than for other intraoral scanners. In particular, digital maxillomandibular registration scan times were shorter than those for conventional techniques.

### Table 4 Time required for direct digitalization and conventional impression

<table>
<thead>
<tr>
<th>Intraoral scanner</th>
<th>Impression range</th>
<th>Material of conventional impressions</th>
<th>Preparation</th>
<th>Impression</th>
<th>Total</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Digital</td>
<td>Conventional</td>
<td>Digital</td>
</tr>
<tr>
<td>CEREC</td>
<td>Full arch (maxillary)</td>
<td>Polyether</td>
<td>33 s</td>
<td>47 s</td>
<td>1 m 42 s</td>
<td>4 m</td>
</tr>
<tr>
<td>Omnicam</td>
<td>Full arch (mandibular)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEREC Bluecam</td>
<td>Single abutment</td>
<td>Polyether /Vinyl polysiloxane /Vinylsiloxanether</td>
<td>1 m 46 s</td>
<td>30 s /1 m /5 m</td>
<td>23 s</td>
<td>4 m</td>
</tr>
<tr>
<td>iTero</td>
<td>Single abutment</td>
<td></td>
<td>1 m 57 s</td>
<td>23 s</td>
<td></td>
<td>3 m 8 s</td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td></td>
<td>1 m 42 s</td>
<td>1 m 18 s</td>
<td></td>
<td>3 m 58 s</td>
</tr>
<tr>
<td>Full arch</td>
<td></td>
<td></td>
<td>2 m 54 s</td>
<td>4 m 44 s</td>
<td></td>
<td>10 m 49 s /11 m 45 s /15 m 45 s</td>
</tr>
<tr>
<td>Lava Chairside Oral Scanner</td>
<td>Single abutment</td>
<td></td>
<td>2 m 16 s</td>
<td>1 m 42 s</td>
<td></td>
<td>4 m 53 s</td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td></td>
<td>1 m 58 s</td>
<td>2 m 12 s</td>
<td></td>
<td>5 m 18 s</td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td></td>
<td>2 m 21 s</td>
<td>6 m 45 s</td>
<td></td>
<td>12 m 30 s /11 m 45 s /15 m 45 s</td>
</tr>
<tr>
<td>Lava Chairside Oral Scanner</td>
<td>Full arch</td>
<td></td>
<td>2 m 09 s</td>
<td>4 m 38 s</td>
<td>7 m 45 s</td>
<td>8 m 9 s</td>
</tr>
<tr>
<td>3Shape TRIOS</td>
<td>Quadrant</td>
<td>Polyether</td>
<td>7 m</td>
<td>7 m 48 s</td>
<td>7 m 33 s</td>
<td>11 m 33 s*</td>
</tr>
</tbody>
</table>

Ref. 21 and 22 data are revised from an original data.

*: Impression of antagonist (Irreversible hydrocolloid) and maxillomandibular registration (Wax) are included in impression time.

### Table 5 Time required for maxillomandibular registration and antagonist for direct digitalization and conventional impression

<table>
<thead>
<tr>
<th>Intraoral scanner</th>
<th>Impression range</th>
<th>Material of conventional impressions</th>
<th>Maxillomandibular registration</th>
<th>Antagonist</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Digital</td>
<td>Conventional</td>
</tr>
<tr>
<td>CEREC Omnican</td>
<td>Full arch</td>
<td>Polysiloxane</td>
<td>14 s</td>
<td>1 m 31 s</td>
<td>21</td>
</tr>
<tr>
<td>CEREC Bluecam</td>
<td>Single abutment</td>
<td>Polydimethylsiloxane</td>
<td>16 s</td>
<td>1 m 30 s</td>
<td>22</td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td>Alginate</td>
<td>17 s</td>
<td>31 s</td>
<td></td>
</tr>
<tr>
<td>iTero</td>
<td>Single abutment</td>
<td>Polydimethylsiloxane</td>
<td>15 s</td>
<td>43 s</td>
<td></td>
</tr>
<tr>
<td>Quadrant</td>
<td></td>
<td></td>
<td>15 s</td>
<td>45 s</td>
<td></td>
</tr>
<tr>
<td>Full arch</td>
<td></td>
<td></td>
<td>29 s</td>
<td>4 m 30 s</td>
<td></td>
</tr>
<tr>
<td>Lava Chairside Oral Scanner</td>
<td>Single abutment</td>
<td></td>
<td>9 s</td>
<td>1 m 30 s</td>
<td>17</td>
</tr>
<tr>
<td>Oral Scanner</td>
<td>Quadrant</td>
<td></td>
<td>12 s</td>
<td>56 s</td>
<td></td>
</tr>
<tr>
<td>Full arch</td>
<td></td>
<td></td>
<td>33 s</td>
<td>4 m 30 s</td>
<td></td>
</tr>
<tr>
<td>Lava Chairside Oral Scanner</td>
<td>Quadrant</td>
<td>Bis-acrylic</td>
<td>42 s</td>
<td>1 m 33 s</td>
<td>17</td>
</tr>
<tr>
<td>Oral Scanner</td>
<td>Full arch</td>
<td>Alginate</td>
<td>1 m 18 s</td>
<td>1 m 20 s</td>
<td></td>
</tr>
</tbody>
</table>

Ref. 21 and 22 data are revised from the original data.

### Assessment of digital impressions

A clinical study of patients answering a 9-item comparative questionnaire (21) found that digital impression techniques yielded better results than did conventional impression techniques. The questionnaire assessed overall impression discomfort, overall impression time, smell/taste/heat, queasiness, discomfort during mouth opening, temporomandibular joint discomfort, breathing difficulty, and tooth and periodontal sensitivity. Gjelvold
et al. (23) reported that visual analog scale assessments of dentists and patients showed greater comfort and less difficulty with a digital impression technique than with conventional impression techniques.

**Clinical performance**

Gherlone et al. and Selz et al. examined the clinical performance of zirconia-based restorations and fixed dental prostheses fabricated with digital impression CAD/CAM systems equipped with intraoral scanners (24,25). Gherlone et al. (24) reported that the chipping rate for the veneering material was 30.2% during a 3-year follow-up period. The chipping rate for all-ceramic restorations increased exponentially from 24 to 36 months, and the success rates were 86.0% after 24 months and 69.8% after 36 months. Selz et al. (25) found that fixed dental prostheses luted with self-curing luting agent did not result in secondary caries, change in anatomic form, endodontic complications, or loss of retention after 18 months of follow-up, but the rate of unacceptable marginal adaptations (visible evidence of crevices and/or catch of a dental explorer; no explorer penetration) were 4.0% after 6 months and 8.0% after 18 months. In addition, marginal discoloration (superficial discoloration at the margin between the restoration and the tooth structure; no penetration in pulpal direction) was 8.0% after 18 months, and color mismatch of the adjacent tooth (mismatch between the restoration and tooth structure; no penetration in pulpal direction) was 4.0% after 18 months. An increase in surface roughness was observed in 21.0% of patients after 6 months and in 35.0% of patients after 18 months. The rate of chipping fracture was 8.0% after 18 months. On subjective assessments, dentists and patients were highly satisfied with the overall aesthetic and functional outcomes of all-ceramic fixed dental prostheses resulting from a digital workflow.

**Discussion**

Conventional fabrication of dental restorations and fixed dental prostheses utilizes lost-wax technique. During the previous decade, CAD/CAM systems were introduced as an alternative technique. Such systems mainly use extraoral scanners for indirect digitalization of stone casts. In Japan, composite resin-based CAD/CAM restorations have been covered by health insurance since 2014.

Digital impression systems using intraoral scanners have improved. However, studies (26-28) reported that information obtained by intraoral scanning was less accurate than that obtained by extraoral digitalization of stone casts and that the former is affected by intraoral conditions such as saliva, blood, limited spacing, preparation shape, and scanning position. Therefore, the impression technique should be selected in accordance with clinical conditions.

Digital impression systems have two classes. Some digital impression systems require coating powder before impression. Clinically, marginal gaps are affected by powder when intraoral scanners are used. However, all marginal gaps for dental restorations and fixed dental prostheses fabricated with intraoral scanners were less than 120 µm, within the range of in vivo reports (15-20,29). These results were regarded to be as clinically acceptable as those obtained by indirect digitalization.

The most distinctive feature of digital impression techniques is total impression time, which tends to be shorter than for conventional techniques. In addition, maxillomandibular registration times are noticeably shorter. Furthermore, two studies (15,30) found that ceramic restorations fabricated from intraoral scans had equal or better interproximal contact point quality and occlusal point quality as compared with ceramic restorations from conventional impressions. Thus, occlusal and interproximal contact adjustment were effective. In addition, total chair time is likely to be shorter. These characteristics will increase the uptake of intraoral scanners in dentistry.

Use of digital impression systems will gradually increase in dental practice. However, the present findings indicate that use of digital impression systems with intraoral scanners for fabrication of dental restorations and fixed dental prostheses requires that the operator understand the characteristics and adaptations required when using intraoral scanners, as these systems can reduce patient discomfort during impression-making.

A number of Japanese studies investigated digital impression systems with intraoral scanners in the second half of 2017. A study of the 3Shape TRIOS noted that an intraoral scanner did not significantly differ from extraoral scanners with regard to trueness of marginal value (31). Studies in all areas of prosthodontics are examining digital impression with intraoral scanners (32). Further discussions are expected to culminate in health insurance reimbursement for use of digital impression systems with intraoral scanners in Japan.

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Conflict of interest
The authors have no conflict of interest to declare.

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