The use of intraoral scanners for acquiring direct digital impressions is becoming more common in the field of fixed prosthodontics. This phenomenon is primarily due to the numerous advantages deriving from their utilization—for instance, intraoral digital scanning could be faster and more comfortable for patients and make it possible to replace physical dental casts with virtual ones, which are more easily stored and shared. Finally, digital models also represent the starting point of the computer-aided design/computer-assisted manufacturing (CAD/CAM) phase.

Despite the obvious advantages related to intraoral scanning, it is essential to investigate whether digital impressions could establish themselves as an appropriate alternative to conventional impressions considering accuracy. This attribute represents a necessary condition for proper adaptation of a fixed prosthesis. On this matter, accuracy is defined as the combination of two elements, trueness and precision, which are both necessary and complementary. Truefulness is described as the ability to capture the real entity of a measure, and precision is defined as the ability to catch the same measure with subsequent samplings.

Despite the huge number of papers exploring this subject, few studies have investigated the performance of a digital intraoral scanner in vivo in the context they are.
meant to be used. In this context, patients’ movements and the presence of blood, saliva flow, and crevicular fluid covering tooth surfaces may lead to scanning errors.\textsuperscript{17,18} On the other hand, assessing trueness in vivo is restricted by the fact that the real geometry of dental arches is unknown. Nonetheless, it is useful to compare direct digital impressions to conventional impressions as a reference, since analog impressions are still regarded as the gold standard in the field of fixed prosthodontics. Consequently, in the present review, only studies comparing digital scanning to conventional impressions made with highly accurate impression materials that are usually involved in the fixed prosthodontic workflow, such as polyether and polyvinyl siloxane, were included.

The aim of the present review was to determine the accuracy of direct digital impressions in vivo and compare it to that of conventional impressions in order to assess whether intraoral scanners could be a legitimate substitute to analog impressions for the manufacturing of fixed prosthodontics.

**MATERIALS AND METHODS**

**Search**

Based on the PICO (population, intervention, comparison, outcome) criteria, a search strategy was executed using an electronic search. The PICO question was formulated as follows: In patients with completely or partially edentulous dentitions or edentulous arches, are digital impressions obtained with intraoral direct scanning in vivo as accurate as analog impressions made with high-precision impression materials?

An electronic search was conducted in the following databases: PubMed, Cochrane Library, Web of Science, and Embase. The research included the period from inception in January 1991 to March 1, 2019, and searched only articles written in the English language. The following query terms were used: digital impression; intraoral digital impression; intraoral scanner; conventional impression; analogue impression; and accuracy. Those terms were combined by the Boolean operators OR/AND in order to widen the search field. The search strategies used in each database are presented in Table 1.

**Table 1 Search Strategy for Each Database and Corresponding Results**

<table>
<thead>
<tr>
<th>Database</th>
<th>Search strategy</th>
<th>No. of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>PubMed</td>
<td>digital impression OR intraoral digital impression OR intraoral scanners AND intraoral digital scanner AND conventional impression OR analogue impression AND accuracy.</td>
<td>74</td>
</tr>
<tr>
<td>Cochrane Library</td>
<td>digital impression AND conventional impression AND accuracy</td>
<td>2</td>
</tr>
<tr>
<td>Web of Science</td>
<td>‘digital impression’ OR ‘intraoral digital impression’ OR ‘intraoral scanner’ OR ‘intraoral digital scanner’ AND ‘conventional impression’ OR ‘analogue impression’ AND ‘accuracy’</td>
<td>1,590</td>
</tr>
<tr>
<td>Embase</td>
<td>‘digital impression’ OR ‘intraoral digital impression’ OR ‘intraoral scanner’ OR ‘intraoral digital scanner’ AND ‘conventional impression’ OR ‘analogue impression’ AND ‘accuracy’</td>
<td>114</td>
</tr>
</tbody>
</table>

**Eligibility Criteria**

This review included studies focusing on trueness and/or precision of dental impressions made using an intraoral scanner in comparison to analog impressions made with high-precision impression materials recorded in vivo. In detail, the paper had to meet the following criteria in order to be included in the review: published in English; in vivo; compare intraoral scanning accuracy (trueness and/or precision) to that of analog impression with high-precision impression materials; and provide information on the used clinical work steps and technical production. Conversely, the exclusion criteria were established as follows: not published in English; in vitro or ex vivo; case report, case series, or expert opinion; no specified intraoral scanners, impression materials, or workflow; and use of only clinical methods to assess the accuracy of the impression techniques.

**Study Selection**

Based on the defined eligibility criteria, the study selection was conducted in four steps. In stage 1, a list of titles was obtained from the databases, and titles that clearly did not match the inclusion criteria were excluded. In stage 2, duplicates were excluded and abstracts were screened. The systematic reviews resulting from the search (n = 15) were used to find additional pertinent studies, and the eligible ones were included in the qualitative analysis. In stage 3, the remaining abstracts were screened again in order to exclude articles not meeting the inclusion criteria. In stage 4, the selected articles were obtained and the full texts were analyzed to evaluate the eligibility criteria and to verify their correlation with the subject of the review. Two studies meeting the inclusion criteria referenced in the systematic reviews were also included in the qualitative analysis. The entire process of study selection is portrayed in Fig 1.

**Risk of Bias of Individual Studies**

The QUADAS (Quality Assessment of Diagnostic Accuracy Studies)\textsuperscript{19} tool was employed to assess the risk of bias of the selected studies. This tool is composed of 14 questions concerning relevant methodologic issues that help to estimate the risk of bias of the included studies. The possible answers are yes, no, and unclear (Table 2).
to represent the variety of conditions that occur in common clinical practice.

**Descriptive Analysis**

Six studies were selected for the qualitative synthesis. Four articles\(^\text{15,16,20,21}\) investigated the precision of the impression methods, while two studies\(^\text{18,22}\) focused on their trueness.

To assess precision, the protocol requires making impressions of the same subject with each impression method several times and superimposing these impressions onto each other to check their respective differences. Conversely, to assess trueness, the protocol requires superimposing the dental models obtained from the same subject but with different impression methods.

Five of the selected studies followed almost the same method to compare digital to conventional impressions: both digital and conventional impressions of study participants were achieved; then, conventional impressions were poured in stone and scanned with a laboratory scanner. Afterwards, the stereolithography (STL) files of the impressions were superimposed using a dedicated software in order to evaluate their relative discrepancies. Mühlemann\(^\text{21}\) followed a different protocol: conventional casts made from conventional impressions were scanned with a laboratory scanner, then digital impressions of the same subjects were taken. These digital casts were milled or printed using a CAD/CAM technique and scanned with a laboratory scanner. Finally, the STL files were analyzed to determine whether the milled or printed casts could be a proper alternative to conventional gypsum casts.

In Ender et al,\(^\text{15}\) five volunteers received conventional impressions (full-arch and double-arch triple-tray quadrant impressions) with a high-precision impression material (vinylsiloxanether) and digital quadrant impressions with seven different

**RESULTS**

**Data Items**

The following data were extracted: sample size; inclusion and exclusion criteria; compared methods; recorded measurements; assessed parameters; and statistical tests (Table 3).

**Risk of Bias Within Studies**

Four studies satisfied 9 of the 13 QUADAS items, while one study satisfied 8 of the 13 QUADAS items. Only one study met 7 of the 13 QUADAS items (Table 2). The highest risk of bias was found especially in the selection of study participants, since those subjects’ characteristics were unlikely
digital intraoral systems. Impressions were taken three times for each impression method for each subject and then superimposed. The authors concluded that although the highest precision was found in the conventional full-arch impression group (18.8 ± 7.1 µm), all the tested digital scanners showed clinically satisfying precision for quadrant impressions, even if they exhibited a wide range of precision values (from 21.7 ± 7.4 µm to 49.0 ± 12.4 µm).

Ender et al\textsuperscript{16} repeated the same test in order to assess the precision of different impression systems used to obtain full-arch impressions. Five volunteers received conventional impressions with three different impression materials (polyether, vinylsiloxanether, and alginate), which were poured in stone and scanned extraorally with a laboratory scanner. The participants also received conventional impressions with direct scannable vinylsiloxanether; those same impressions were scanned with a laboratory scanner. Finally, the subjects also received digital impressions with eight different digital intraoral systems. Again, the authors concluded that the highest precision (from 17.4 ± 5.1 µm to 36.7 ± 3.8 µm) belonged to the conventional group with the exception of the alginate subgroup, which, on the contrary, exhibited the worst precision among all the test groups. The different digital impression systems showed a wide range of precision values (from 34.9 ± 8.8 µm to 82.8 ± 39.3 µm). Moreover, the author underlined the difficulty of scanning the anterior region of the dental arch with sufficient accuracy and the chance of propagation of error gradually extending the impression width.

Flügge\textsuperscript{20} investigated the precision of intraoral scanners while acquiring full-arch impressions in vivo. The comparison was represented by a conventional gypsum cast realized using a polyether highly accurate impression material. The conventional cast was scanned multiple times with both a laboratory scanner and an intraoral scanner (iTero, Align Technology) in order to reveal any differences in the scanner performance eventually caused by the intraoral conditions. As documented by Ender et al.,\textsuperscript{15,16} the highest precision yet again belonged to the conventional group with the exception of the alginate subgroup, which, on the contrary, exhibited the worst precision among all the test groups. The different digital impression systems showed a wide range of precision values (from 34.9 ± 8.8 µm to 82.8 ± 39.3 µm). Moreover, the author underlined the difficulty of scanning the anterior region of the dental arch with sufficient accuracy and the chance of propagation of error gradually extending the impression width.

Table 2 QUADAS Analysis for Each Included Study

<table>
<thead>
<tr>
<th></th>
<th>Ender et al\textsuperscript{15}</th>
<th>Ender et al\textsuperscript{16}</th>
<th>Gan et al\textsuperscript{18}</th>
<th>Flügge et al\textsuperscript{20}</th>
<th>Mühlemann et al\textsuperscript{21}</th>
<th>Rhee et al\textsuperscript{22}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the spectrum of patients representative of the patients who will receive the test in practice?</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>N</td>
<td>Y</td>
<td>U</td>
</tr>
<tr>
<td>Were selection criteria clearly described?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Is the reference standard likely to correctly classify the target condition?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>Y</td>
<td>U</td>
</tr>
<tr>
<td>Did the whole sample or a random selection of the sample receive verification using a reference standard of diagnosis?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Did patients receive the same reference standard regardless of the index test result?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Was the reference standard independent of the index test (ie, the index test did not form part of the reference standard)?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Was the execution of the index test described in sufficient detail to permit replication of the test?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Was the execution of the reference standard described in sufficient detail to permit its replication?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Were the index test results interpreted without knowledge of the results of the reference standard?</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Were the reference standard results interpreted without knowledge of the results of the index test?</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Were uninterpretable/ intermediate test results reported?</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Were withdrawals from the study explained?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Score</td>
<td>9/13</td>
<td>9/13</td>
<td>9/13</td>
<td>7/13</td>
<td>9/13</td>
<td>8/13</td>
</tr>
</tbody>
</table>

Y = yes; N = no; U = unclear; N/A = not applicable.
cast exhibited an intermediate amount of precision (25 µm). Thus, these data revealed that intraoral conditions, such as the presence of saliva flow, intraoral humidity, limited space, and patient movement, were able to negatively affect intraoral scanning precision, since extraoral scanning with the same scanner and the same protocol used for intraoral scanning showed better precision. This study also pointed out that the highest deviations were in the buccal surface of the anterior teeth and in the molar region, probably because of the complex shape of the tooth surfaces in those regions. Finally, the authors concluded that it is feasible to use intraoral scanners for obtaining digital models used for treatment planning of a tooth-supported orthodontic appliance.

Mühlemann et al. assessed the precision of digital quadrant impressions and conventional impressions in patients with only one missing tooth replaced by an implant. Contrary to the previous studies, this time, digital models were materially obtained with different CAM systems using both subtractive and additive manufacturing techniques, then scanned with a laboratory scanner. The study showed that despite the similar precision of all the impression techniques in representing the teeth surrounding the implant scan body, conventional impressions exhibited the best precision for the implant analog position, with a mean precision value of 32.7 ± 11.6 µm. The mean precision values of digital impressions were 57.2 ± 32.6 µm for the iTero scanner, 88.6 ± 46 µm for the Trios scanner (3Shape), and 176.7 ± 120.4 µm for the Lava True Definition scanner (3M). This phenomenon may result in a more coronal position of the implant analog and therefore a hypo-occlusion of the final restoration. These outcomes can be explained by many reasons, such as the need to

Table 3  Summary of the Major Data Extracted from the Selected Articles

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>5 subjects from a voluntary collective</td>
<td>5 subjects from a voluntary collective</td>
<td>34 subjects from Shanghai Jiao Tong University School of Medicine</td>
</tr>
<tr>
<td>Inclusion/ exclusion criteria</td>
<td>Complete dentition</td>
<td>Complete dentition</td>
<td>Subjects aged at least 18 years, with good oral hygiene, with complete maxillary dental arch except the missing third molar, with intact hard and soft tissues, including treated teeth decay and healed teeth extraction socket; not undergoing orthodontic treatment, no metal crowns or other metal materials on teeth, no soft tissue lesions and/or postoperative scars on the palate, no oral implants, no advanced periodontitis affecting gingival recession, no obvious tooth mobility, no obvious dentition malalignment</td>
</tr>
<tr>
<td>Compared methods</td>
<td>Conventional full-arch impressions with polyether, vinylsiloxanether, and alginate poured in stone and then scanned with a laboratory scanner, and direct scannable vinylsiloxanether scanned with a laboratory scanner; digital impressions with 3M Lava C.O.S., Cadent iTero, 3Shape Trios, CEREC Bluecam, CEREC Omnicam, 3Shape Trios Color, 3M True Definition Scanner</td>
<td>Conventional full-arch impression and dual-arch quadrant impression with vinylsiloxanether impression material poured in stone and then scanned with a laboratory scanner; digital impression with 3M True Definition Scanner, 3M Lava C.O.S., Cadent iTero, 3Shape Trios, CEREC Bluecam with CEREC software 4.0, CEREC Bluecam with CEREC Software 4.2 (4.2), CEREC Omnicam</td>
<td>Conventional full-arch impression of maxilla with polyvinyl siloxane poured in stone and then scanned with a laboratory scanner; digital impression with an intraoral digital scanner (Trios Pod) of maxilla, including the full dentition and palatal soft tissues</td>
</tr>
<tr>
<td>Recorded measurements</td>
<td>Deviations between corresponding models</td>
<td>Deviations between corresponding models</td>
<td>Deviations between corresponding models</td>
</tr>
<tr>
<td>Assessed parameters</td>
<td>Precision of full-arch impressions</td>
<td>Precision of quadrant impressions</td>
<td>Trueness and precision of full-arch impressions</td>
</tr>
<tr>
<td>Statistical tests</td>
<td>Kolmogorov-Smirnov test; Levene test; Bonferroni test</td>
<td>Kruskal-Wallis test; Levene test; Dunnett T3 test</td>
<td>Kolmogorov-Smirnov test; Levene test; Student t test; least significant difference test; Pearson correlation coefficient</td>
</tr>
<tr>
<td>Conclusions</td>
<td>High-precision impression materials showed better precision than digital methods for full-arch impressions; however, all digital impression methods were capable of measuring complete dental arches.</td>
<td>Conventional full-arch impressions, except for double-arch impressions, showed better precision than digital impressions; however, all digital impression methods were capable of measuring quadrant impressions with clinically satisfying precision.</td>
<td>It is feasible to use intraoral scanners for impressions of the maxilla with satisfying accuracy.</td>
</tr>
</tbody>
</table>

FMPS = full-mouth plaque score; FMBS = full-mouth bleeding score.
Flügge et al\textsuperscript{20} (2013) & Mühlemann et al\textsuperscript{21} (2018) & Rhee et al\textsuperscript{22} (2015) \\
1 subject & 5 subjects & 24 subjects \\
Class I occlusion and complete dentition & Subjects aged at least 18 years; FMPS and FMBS ≤ 25%; no active periodontal disease; presence of a single-tooth implant in need of a crown in regions 14–17, 24–27, 34–37, or 44–47 (FDI); healthy or sufficiently restored adjacent and antagonist teeth & Subjects with Braly Class I or II who had lost a mandibular first molar only and replaced it with an implant; no periodontitis or temporomandibular joint disease or Braly Class III \\
In vivo scans (iTero, group 1) of both mandibular and maxillary arches; conventional impressions of both mandibular and maxillary arches with polyether poured in stone and then scanned with iTero (group 2); and model scanner (3Shape D250, group 3) & Conventional full-arch impression with polyether using closed-tray technique poured in stone and scanned with a laboratory scanner; quadrant scan with three different intraoral scanners (Cadent iTero, 3M Lava True Definition and 3Shape Trios); implant models designed by means of CAD then milled or printed and finally scanned with a laboratory scanner & Digital impression with 3Shape Trios Mono using scannable abutment; full-arch and dual-arch conventional impressions with polyvinyl siloxane impression material poured in stone and then scanned with a laboratory scanner \\
Deviations between corresponding models & Deviations between corresponding models & Deviations between corresponding models \\
Precision of full-arch impressions & Precision of full-arch and quadrant impressions & Trueness of full-arch and quadrant impressions \\
Kolmogorov-Smirnoff test & Kruskal-Wallis test; Conover test; Wilcoxon signed-rank test & One-way ANOVA; Scheffe test \\
Conventional impressions showed the best precision; however, virtual models produced via intraoral scanning could be used for treatment planning and manufacturing of tooth-supported appliances. & Conventional impressions showed significantly better precision compared to digital impressions; independent of the CAD/CAM system used, digital implant models cannot serve as a reliable reference for the dental technician. & The biggest difference was between intraoral scanning and dual-arch impressions, while the smallest difference was between full-arch and dual-arch impressions. The accuracy of intraoral scanning should be further improved for general use. \\

place implant analogs in the digitally milled or printed models manually, the different kind of manufacturing process, or the quality of the CAM devices and the type of materials used for fabricating the models. At last, the authors concluded that implant models realized with intraoral scanners could not be regarded as a reliable reference for the dental technician. Nevertheless, assuming that imprecision is partially due to the manufacturing process itself, a model-free fabrication should be considered.

Rhee et al\textsuperscript{22} tested the trueness of direct digital impressions by comparing them to full-arch and dual-arch conventional polyvinyl siloxane impressions in subjects who had lost a first molar only and had it replaced with an implant. The smallest difference was found between the dual-arch impressions and the full-arch impressions: the deviations between the two models, calculated at the second premolar buccal cusp and second molar buccal cusp, were, respectively, 60.9 µm and –3.4 µm. The biggest difference was found between direct digital impressions and full-arch conventional impressions; the deviations between the two models calculated at the second premolar buccal cusp and second molar buccal cusp were, respectively, 118.9 µm and 80.7 µm. Furthermore, the authors indicated that directly achieved digital models were positioned more apically on the buccal surface than the conventional groups. As affirmed above, this trend may result in a hypo-occlusion of the final restorations. Finally, the author concluded that intraoral scanner accuracy should be improved for general use.

Gan et al\textsuperscript{18} investigated both trueness and precision of full-arch digital impressions of the maxillary dentition. In order to assess trueness, digital models

<table>
<thead>
<tr>
<th>Deviations between corresponding models</th>
<th>Deviations between corresponding models</th>
<th>Deviations between corresponding models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision of full-arch impressions</td>
<td>Precision of full-arch and quadrant impressions</td>
<td>Trueness of full-arch and quadrant impressions</td>
</tr>
<tr>
<td>Kolmogorov-Smirnoff test</td>
<td>Kruskal-Wallis test; Conover test; Wilcoxon signed-rank test</td>
<td>One-way ANOVA; Scheffe test</td>
</tr>
<tr>
<td>Conventional impressions showed the best precision; however, virtual models produced via intraoral scanning could be used for treatment planning and manufacturing of tooth-supported appliances.</td>
<td>Conventional impressions showed significantly better precision compared to digital impressions; independent of the CAD/CAM system used, digital implant models cannot serve as a reliable reference for the dental technician.</td>
<td>The biggest difference was between intraoral scanning and dual-arch impressions, while the smallest difference was between full-arch and dual-arch impressions. The accuracy of intraoral scanning should be further improved for general use.</td>
</tr>
</tbody>
</table>
obtained from intraoral scanning were compared to STL files of scanned gypsum casts produced by conventional polyvinyl siloxane impressions. In addition, the authors also focused on the accuracy of calculation of deviation at the palatal soft tissues, which could be assessed in preparation for the future use of digital impressions for manufacturing of removable partial or complete denture prostheses. When calculated at the palatal soft tissues, the mean deviation between intraoral digital impressions and conventional impressions was 130.54 ± 33.95 µm, while when assessed at the maxillary dentition, it was 80.01 ± 17.78 µm. The major deviations occurred in the anterior teeth and in the molar regions, where it is more difficult to remove saliva on the tooth surfaces and where teeth anatomy could be more difficult for the scanner to completely catch. Moreover, the study did not test precision of analog impressions, but investigated only the precision of digital impressions by comparing them to other impressions from the same volunteer. The results showed a mean deviation of 55.26 ± 11.21 µm for the palatal soft tissues and 59.52 ± 11.29 µm for the full dentition, with irregular deviations across the whole maxilla. The authors stated that although the arch width did not influence digital impression trueness, it could affect precision, where the larger the scanned region, the greater the imprecision. Furthermore, the authors assessed that the palatal vault height might have no effect on digital impression accuracy. The authors concluded that, in light of the study results, it is feasible to use an intraoral scanner to obtain a digital impression for the whole maxilla.

The results of the studies are summarized in Table 4.

DISCUSSION

The growing interest in the utilization of digital technology in restorative dentistry is confirmed by the huge number of scientific publications concerning this subject, which has more than doubled in the last 10 years.10 Nonetheless, the increase in published articles does not correspond to a substantial increase in relevant data, since the majority of the information results from in vitro studies. In vivo trials are supported by higher scientific evidence and could elucidate the limits that affect the performance of digital scanners when used in a clinical context. Thereby, clinical studies may provide manufacturing industries with the input to overcome these deficiencies, promoting progress in digital dental technologies. Furthermore, in vivo experimentations could help dentists in practice by describing the proper technique for enhancing the quality of the performance of the digital workflow in a clinical situation.

An additional threshold to the present analysis is the lack of a unanimous agreement on the clinically tolerable values of the accuracy of dental impressions. Conversely, scientific literature has expressed itself many times on the proper accuracy of a fixed prosthesis, stating that after cementation, the marginal gap and the internal gap should be, respectively, up to 120 µm and from 50 to 100 µm.23 Consequently, it can be affirmed that impressions that exhibit a level of inaccuracy greater than these values are not feasible for clinical purposes. Moreover, it should be underlined that both analog and digital manufacturing procedures are subjected to errors that may result in a misfit of the restoration. For these reasons, the inaccuracy values for both conventional and digital impressions should be considered stricter than the ones used for indirect restorations.

Given this background and notwithstanding the higher precision and accuracy of the analog technique, all intraoral scanners (except for the Lava True Definition Scanner in the paper by Mühlemann21) showed accuracy and precision falling within the benchmark limits. The selected studies reported different values of accuracy, ranging from 21.7 ± 7.4 µm to 176.7 ± 120.4 µm for precision and from 80.01 ± 7.78 µm to 118.9 µm for trueness. The wide range of results is likely due to the different types of intraoral scanner used and to the various conditions in which they have been applied. Indeed, the selected studies reported the results obtained by using various digital scanners that belong to multiple generations and that make use of different scanning technologies. For these reasons, it was not possible to compare the results of the selected studies.

Four of the selected studies assessed the precision of both digital and conventional impressions. Ender et al15 and Flügge20 concurred in claiming that intraoral scanners are sufficiently precise for being used in vivo. The results in Mühlemann et al21 were in agreement with considering analog workflow as the most precise method for impression-taking; however, that trial also highlighted that even if digital scanners were able to represent the geometry of natural teeth with sufficient precision, this was not true for implant analogs in physical models obtained from CAM technologies. This result suggests that, when fabricating a prosthesis over implants, a complete model-free digital workflow that avoids the fabrication of a physical milled or printed cast is preferable.

Analysis of the included papers shows that arch width could negatively affect the precision of digital impressions.15,16,18 This trend could be correlated with the “merging” errors committed by the digital scanner software when piecing together different images obtained from scanning to create a three-dimensional model, so that the larger the scanning region, the less repeatability might occur.18,24–26

Only two studies18,22 in the present selection investigated the trueness of digital impressions using conventional models as a reference. In both cases, the
that intraoral scanners should be further improved before being used in a clinical context.

Regarding the factors influencing the accuracy of digital impressions, Gan\textsuperscript{18} and Flügge\textsuperscript{20} agreed that the greater amount of inaccuracy was found in the molar and anterior regions because of the complex angles and amount of discrepancies when superimposing digital models onto conventional ones was higher than the values resulting from precision assessment. At the same time, the authors interpreted these findings in a different way. While Gan et al\textsuperscript{18} believed that direct digital impressions are sufficiently accurate, Rhee\textsuperscript{22} considered that intraoral scanners should be further improved before being used in a clinical context.

Regarding the factors influencing the accuracy of digital impressions, Gan\textsuperscript{18} and Flügge\textsuperscript{20} agreed that the greater amount of inaccuracy was found in the molar and anterior regions because of the complex angles and amount of discrepancies when superimposing digital models onto conventional ones was higher than the values resulting from precision assessment. At the same time, the authors interpreted these findings in a different way. While Gan et al\textsuperscript{18} believed that direct digital impressions are sufficiently accurate, Rhee\textsuperscript{22} considered that intraoral scanners should be further improved before being used in a clinical context.
undercut surfaces of molars and the complex shape of the teeth made by steep areas for incisors. These data may give suggestions for tooth preparation design so that the teeth can be more accurately read by the intraoral scanner. Indeed, these results suggest that smooth and undercut-free preparation are to be preferred. More evidence on this possibility is needed.

As previously affirmed, these publications compare digital models to conventional ones. Although impression materials can be considered highly accurate, they always show a certain degree of inaccuracy. In addition, the realization, manipulation, storage, and application of impression materials such as conventional gypsum casts are capable of introducing a certain degree of error in the workflow; therefore, the discrepancies between digital models and the real geometry of the scanned object could be even bigger than the values reported in the mentioned studies. Therefore, the summation of inaccuracies produced at different stages of the workflow may lead to a misfit between the restoration and underneath the tooth or implant. This phenomenon could cause biologic complications such as secondary caries, endodontic and periodontal disease, or peri-implantitis, as well as mechanical complications like decementation or the breaking of the restoration itself.

An additional limit for the present analysis is that in the selected papers, the sample used to assess the accuracy of intraoral scanners was composed of intact teeth. Hence, the possible consequences of tooth shape after tooth preparation remain unknown. This is an aspect that requires further research, since the performance of digital scanners is strictly connected to the shape of the scanned objects.18–27

Additionally, there is little information about the influence of the impressed substrates. Bocklet et al28 found enamel, along with amalgam restorations, to be the least true and precise substrate for the intraoral scanner, and dentin and composite to be truer and more precise. This evidence suggests that a greater level of accuracy of digital impressions on prepared teeth, in respect to intact teeth, is possible. However, there are few clinical data about this topic. More information on this issue is needed, since the shape and reflectivity of the substrate are likely to overwhelmingly affect the accuracy of intraoral scanners.

Additionally, it should be noted that all of the selected studies included subjects with complete dentition or only one tooth missing. Studies assessing the accuracy of intraoral scanners in the partially edentulous mouth are needed. The absence of teeth causes a lack of reference points both for the clinician and the scanner itself9,24,29; thus, a decrease in the accuracy of digital impressions in those cases is expected.

Moreover, three of the six papers included in the present review excluded subjects with periodontitis and tooth decay. Gan et al18 also excluded subjects with metal crowns or other metal materials on teeth. This aspect limits the collected evidence to a very restricted number of cases that the dentists usually treat in their clinical daily routine.

Finally, another limitation for the present discussion is that only six papers were included in the review, and five of them are relatively outdated compared to the speed at which digital technologies are progressing. Significant information about more recent intraoral scanners is lacking. Finally, it will be significant to assess the fit of indirect restorations realized with a completely digital workflow.

CONCLUSIONS

According to the results of the present review, high-precision conventional impressions are more accurate than digital impressions in vivo. Nevertheless, the authors take different positions on the ability to use intraoral scanners in a clinical setting without this leading to a decrease in accuracy of the final restorations. Moreover, significant evidence regarding multiple points about the performances of these technologies in vivo is lacking and not up to date. For these reasons, additional studies focusing on the accuracy of the latest models of intraoral scanners in a clinical context are strongly recommended.

ACKNOWLEDGMENTS

The authors report no conflicts of interest.

REFERENCES


Literature Abstract

Accuracy of Single Molecular Biomarkers in Gingival Crevicular Fluid for the Diagnosis of Periodontitis: A Systematic Review and Meta-Analysis

The aim of this study was to analyze, by means of a meta-analytic approach, the diagnostic accuracy of molecular biomarkers in gingival crevicular fluid (GCF) for the detection of periodontitis in systemically healthy subjects. Studies on molecular biomarkers in the GCF providing a binary classification table (or sensitivity and specificity values and group sample sizes) in individuals with clinically diagnosed periodontitis were considered eligible. The search was performed in six electronic databases. The methodologic quality of studies was assessed using the Quality Assessment of Diagnostic Studies tool. Meta-analyses were performed using hierarchical summary receiver operating characteristic, which adjusts classification data using random-effects logistic regression. The included papers identified 36 potential biomarkers for the detection of periodontitis, and meta-analyses were performed for 4 of them. The median sensitivity and specificity values for MMP8 were, respectively, 76.7% and 92.0%; for elastase, 74.6% and 81.1%; and for cathepsin, 72.8% and 67.3%. The worst estimates of sensitivity and specificity were for trypsin (71.3% and 66.1%, respectively). MMP8 showed good sensitivity and excellent specificity, which resulted in this biomarker being clinically the most useful or effective for the diagnosis of periodontitis in systemically healthy subjects, regardless of smoking condition.