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SYSTEMATIC REVIEW

Digital scanning for complete-arch implant-supported restorations: A systematic review

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ABSTRACT

Statement of problem. Scanning of completely edentulous arches remains a challenge because of the large surface to scan and the lack of anatomic indexes. Whether the presence of impression transfer copings with digital scanning provides enough markers for acceptable precision and clinical use has not been determined.
**Purpose.** The purpose of this systematic review was to assess the accuracy of digital scanning for complete-arch implant-supported restorations.

**Material and methods.** A systematic review of peer-reviewed literature was conducted to analyze articles published between 2008 and 2019. Among the 208 retrieved articles, 20 were selected for review.

**Results.** Five articles reported the use of digital scanning in clinical situations and satisfying short-term results. Fifteen in vitro studies were also included for complementary information, including measurement accuracy. Most of the intra-oral scanners used in vitro provided acceptable accuracy below a threshold of 150 µm. When directly compared, the digital technique was at least equivalent to conventional impression techniques.

**Conclusions.** In vitro, intra-oral scanners have shown acceptable accuracy. The main parameters identified for their influence on precision were interimplant distance, body scan design, scanning pattern, and operator experience. Clinical evidence is limited by the lack of a definitive method of assessing the fit of the framework.

**CLINICAL IMPLICATIONS**

Digital scanning may enhance patient comfort, acquisition speed, and precision for complete-arch implant-supported restorations. Studies of in vitro measurements support these advantages. Clinical use may depend on interimplant distance, body scan design, scanning pattern, and operator experience.

**INTRODUCTION**
Patients with complete dentures have benefitted from the use of implants to improve masticatory efficiency. A recent meta-analysis reported high implant and prosthesis survival rates for fixed rehabilitations and was supported by studies describing fixed dentures on 4 to 6 maxillary implants or 4 mandibular implants. The main remaining difficulties with these restorations include accuracy for a better prosthesis fit. In this context, the conventional procedures of impression-making appeared to have room for improvement.

Conventional implant impressions for edentulous patients are unpleasant and are associated with the risk of deformation and triggering the gag reflex. Moreover, most of the studies advocate splinting the impression copings to maximize accuracy, a procedure requiring time and discomfort for the patient, whose mouth must remain open during the procedure. Furthermore, the laboratory steps may add errors to this conventional workflow. A lack of accuracy of the definitive cast results in misfit of the fixed prosthesis, which cannot be compensated by periodontal ligaments and may lead to implant or prosthetic complications, such as screw, ceramic, or implant fracture or peri-implant bone loss.

By limiting the technical procedures and contact with the oral mucosa, optical scanning might improve patient comfort. These technologies rely on triangulation, confocal imaging, active wavefront sampling, or stereophotogrammetry to determine the distance to the object. Scan bodies, specific to optical technologies, need to be screwed or snapped on the implant or abutment to adequately transmit the 3D implant position. Hovering over the dental arch, the optical scanner produces a digital file. This digital workflow overcomes the physical steps associated with potential errors in accuracy, such as disinfection, storage, shipping, and gypsum pouring. Implant scanning in partially edentulous patients has been found a clinically acceptable alternative to physical impressions.
The use of digital scanning for completely edentulous arches has been questioned. The surface area to be scanned increases the risk of angulation errors due to an accumulation of registration errors of the patched 3D surfaces, especially in the mandible, as was shown with dentate arches.\textsuperscript{12-15} Moreover, because of the lack of anatomic relief,\textsuperscript{16-18} mucosal changes during mandibular movements,\textsuperscript{19} and similarity of the morphology of the scan bodies, their 3D individualization is complex.\textsuperscript{20,21}

Few studies have focused on the optical scanning of complete-arch implant-supported prostheses, and the results are inconsistent. The purpose of this systematic review was to assess the accuracy of the optical scanning of multiple implants in edentulous patients. The null hypothesis was that the optical scanning of multiple implants in edentulous patients would have similar accuracy to the physical impressions of splinted copings.

**MATERIAL AND METHODS**

The patient-intervention-control-outcome (PICO) question in this systematic review was “Is intraoral digital scanning a clinically acceptable technique for complete-arch implant-supported prostheses?”

Medline(Pubmed), Cochrane, and Web of Science databases were searched for articles published in the past decade (Table 1). The references cited in the articles included were verified. Inclusion criteria were clinical studies using digital scanning for complete-arch implant-supported (conventional or immediate) restorations that reported the related outcomes. All studies were original articles published in English in a peer-reviewed journal. Experimental studies of digital scanning for complete-arch implant restorations on edentulous models were also included. Literature reviews, case reports, abstracts, and articles that described digital
scanning for partially edentulous situations or orthodontic use were excluded.

Two reviewers (C.W., A.N.) performed the literature search independently until March 2019. All titles and abstracts of the retrieved articles were analyzed and selected in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Papers meeting the inclusion criteria or presenting insufficient data in the title and the abstract for a decision were selected for full analysis. The 2 reviewers assessed the full-text articles independently. Any disagreement on the eligibility of studies was resolved by discussion and consensus. The reviewers tabulated selected data from the included articles according to the number of implants, the arch (maxilla or mandible), the implant angulation, the accuracy results, the control (use of conventional impression as control, conventional impression technique), measurement strategies, and calibration. Follow-up duration and clinical outcomes were extracted for clinical studies. A meta-analysis was considered inappropriate because of the high degree of heterogeneity of studies in terms of design and methodologies.

RESULTS

After database screening and the removal of duplicates, 208 articles were retrieved (Fig. 1); reports for 70 studies remained after title screening and 32 after examining abstracts. The full texts of the 32 studies were further assessed for eligibility. Twelve studies were excluded because they reported digital scans of edentulous jaws without implant,18 dentate arches,12,22,23 or partially edentulous arches.24-29 One study was excluded because it described physical impressions only30 and another because it was a clinical report.31 A total of 20 studies published after 2008 were analyzed.

Two main technologies are available for digital scanning: confocal microscopy associated
with 3D imaging technologies (Table 2) and photogrammetry. Photogrammetry relies on photographic images to record the geometrical properties of 3D objects (optical targets) and their interrelated spatial positions.

Only 5 clinical studies were retrieved: 1 pilot study, 1 prospective study, and 3 randomized controlled trials (RCTs), with a follow-up of 1 to 2 years. In the Gherlone et al RCT, 30 complete-arch implant restorations in 25 patients were followed for 1 year. The quality of the impression was assessed by intra-oral radiographic control of marginal discrepancy between the implants and the prosthetic framework. Peñarrocha-Diago et al followed 21 complete-arch restorations for 14 months. The authors used radiographic measurement of the prosthetic framework marginal fit when it was screwed on only 1 posterior implant (Sheffield test). The three RCTs reported 100% implant and prosthetic survival rate. Bone loss did not differ by digital scanning or conventional impression. The authors concluded that digital scanning could realize a clinically acceptable prosthesis and was equivalent in accuracy to conventional impression (polyether material with an open-tray technique). However, in the pilot study, digital clinical measurements were compared with measurements performed on conventional casts that had previously served for soldered bar fabrications. The authors were dissatisfied with the precision of the intra-oral scanner.

Most in vitro studies focused on intra-oral scanner accuracy and precision as compared with coordinate measurement machines or laboratory optical scanners. Coordinate measurement machines are considered the gold standard, with an accuracy of 1 µm, whereas extra-oral scanners reach 6-µm accuracy.

Most authors agreed on the definition of trueness, accuracy, and precision. Trueness is defined as the comparison between a control dataset and a test dataset. The measured deviations
between the control dataset and test dataset determined the accuracy. Precision resulted from a comparison among different datasets obtained with the same scanner. However, results were conveyed with different outcomes: trueness and precision,\textsuperscript{20} general and local trueness and precision,\textsuperscript{33,35} linear and angular deviation,\textsuperscript{37} root mean square error of superimposition,\textsuperscript{19,36} average measurement error,\textsuperscript{42} and bias error value.\textsuperscript{32} These measurements were related to a measurement method that involved a comparison of linear or angular measurement in a coordinate system,\textsuperscript{32,42,43} measurement of deviation with the zero method with 1 of the implants used as the reference,\textsuperscript{17,33,35,39,48,49} or measurement of deviation after the superimposition of standard tessellation language (STL) files of the master model and the digital scan by a best-fit algorithm that tended to average repositioning.\textsuperscript{19,20,33-37} With such disparities, no mean accuracy value could be calculated. An overview of accuracy obtained with the different systems is presented in Table 3.

One study measured the marginal fit discrepancy of the prosthetic framework on the original master model with an optical microscope.\textsuperscript{38} In another, the misfit was measured by applying the Sheffield test.\textsuperscript{39}

Comparison between digital scanning and conventional impression involved using polyether, silicone, or plaster materials and various impression techniques (open or closed tray, splinted or nonsplinted).\textsuperscript{19,34,36-39,42,43} However, the control tended to be a splinted polyether open-tray impression. All studies concluded that digital scanning was at least equal and sometimes better than conventional impressions, considering the limitation of in vitro evaluations.

**DISCUSSION**
The use of digital scanning is spreading in general practice, from single tooth restoration to orthodontic treatment. The advantages are numerous: comfort for the patient and the practitioner, the appeal of advanced technology, and a shortened prosthetic workflow. However, complete-arch implant restorations seem the most challenging clinical situation for introducing digital scanning. The objective of this systematic review was to assess the accuracy of optical impressions of multiple implants in edentulous patients. Only 5 in vivo studies were included in the review, so 15 in vitro studies focusing on the specific situation of complete edentulism were also considered for additional information, particularly experimental measurements. Because of the limited number of clinical studies available, all studies were included whatever the methodological quality of the protocol regarding the randomization method, allocation concealment, blinding, or drop-out rate. Only 1 clinical report was excluded.

This review supported the null hypothesis that optical impressions of multiple implants in edentulous patients may be as accurate as physical impressions of splinted copings. On the basis of in vitro evidence, this technology could still be considered appropriate for clinical use in terms of accuracy. The main limitations are the limited number of clinical studies to ensure that in vitro results can be extrapolated to clinical conditions and the lack of studies with long-term follow-up.

Accuracy is the major issue when considering the quality of digital scanning because it relates to the definitive fit of the prosthesis. The threshold for misfits not inducing clinical complications is generally considered to be 150 µm.

In the analyzed studies, accuracy was measured in different clinical scenarios, with 4 to 6 implants always homogeneously distributed on the maxilla or the mandible in the interferammina zone (Table 3). The distance of the more distal implant was a cause of inaccuracy, but the
effect of the number of implants was never specifically studied. Furthermore, no study measured the linear or angular distortion at the level of the more distal implant as a function of distance and number of implants. This topic would have been interesting because the lack of reference features on the mucosa and the risk of confusion between impression transfers were often cited as uncertainties impairing the feasibility of digital scanning in the edentulous arch.\textsuperscript{20,21}

Alikhasi et al\textsuperscript{37} investigated the effect of connection types (external or internal) on accuracy based on measuring linear and angular distortions. Digital scanning revealed no difference in accuracy by connection type, whereas external connections allowed for easier removal of conventional impressions and thus generated less deformation.\textsuperscript{34} All authors used digital scanning transfers at the implant level.

The effect of implant angulation was thoroughly explored, with different intra-oral scanners and degree of tilting from 10 to 45 degrees. Most authors agreed that angulation had no effect on accuracy with digital scanning,\textsuperscript{17,19,34,36,37,48} unlike conventional impressions.\textsuperscript{19,36,37,53} Alikhasi et al\textsuperscript{37} reported that the operator had to apply more force during conventional impression removal with tilted implants. In their clinical studies, Gherlone et al\textsuperscript{45,46} used digital scanning for all-on-four restorations with posterior tilted implants and reported 100% survival after 1 year.

Giménez et al\textsuperscript{48} also studied the effect of the depth of the implant platform on the accuracy of digital scanning. The authors found no effect with Omnicam\textsuperscript{17} but better accuracy for subgingival implants with iTero.

Most commercial systems using 3D imaging technologies offer impression transfers, or scan bodies, made of polyetheretherketone (PEEK), a polymer with high mechanical properties. These scan bodies are screwed directly into the implant.\textsuperscript{17,19,20,33-37,45,46,48} Recently, powdering
scan bodies is less often necessary but is still required with Lava Cos and True Definition scanners. The impression transfer can affect the impression accuracy at different levels: its fit with the implant, its geometry, and its wear. Stimmelmayr et al\textsuperscript{54} reported a mean discrepancy between PEEK scan bodies and implants of 39 µm. Fluegge et al\textsuperscript{21} stated that the design of the scan body influenced the precision of the impression and recommended longer and larger scan bodies. The authors also verified that 10 repeated detachments and re-attachments of the PEEK scan body were not detrimental to the scanning precision.\textsuperscript{21}

Using the photogrammetry principle, Del Corso et al\textsuperscript{32} scanned transfers made of white opaque cylinders assembled on a stainless steel base. Another group used homemade targets with spheres coated with a reflective material.\textsuperscript{42,43} In the Precise Implants Capture(PIC) system, flag-shaped targets encoded the implant anatomic position.\textsuperscript{31,41,44,55} With more than 5 implants, the digital scan consisted of a series of 60 photographs for each pair of implants and required a 2-phase registration because of the flag size.\textsuperscript{44}

One study proposed the splinting of transfers to reproduce the conditions of conventional impressions. This issue was not further discussed.\textsuperscript{40}

Digital scanning technology has not yet reached maturity, so innovation will further optimize all systems. Studies comparing intra-oral scanners or digital and conventional impressions and randomized clinical trials provide some comparison elements. A direct comparison of cameras recommended the TRIOS and CS 3600, which are widely used.\textsuperscript{20,33,35,36} Comparison of the performance of the TRIOS3, Omnicam, True Definition, and iTero with conventional impressions generally favored the digital systems, or the systems were at least equivalent.\textsuperscript{19,34,36,38,39} Finally, RCTs assessed short-term clinical success with the TRIOS, CS 3600, and Precise Implants Capture photogrammetric system.\textsuperscript{40,41,46}
Comfort for the patient and reduced chair time are often used as arguments in favor of
digital scanning. Gherlone et al\textsuperscript{46} reported that the digital technique required significantly less
time than the conventional technique (7.57 ±3.08 versus 18.23 ±5.38 minutes). The authors also
considered the additional time required for a partial rescan or retake. Digital scanning more
frequently required retakes but demanded less time.\textsuperscript{40} Also, in vivo photogrammetry scanning
required less time than conventional impressions (15:40 versus 27:06 minutes).\textsuperscript{41} In the same
study, the authors asked patients to score their satisfaction on a visual analog scale, which
showed a significant difference in favor of photogrammetry.\textsuperscript{41} Small mouth opening did not
affect the precision of the technique.\textsuperscript{43}

Reduced chair time and material costs might convince most technology-enthusiastic
dentists. Gherlone et al\textsuperscript{46} measured operator satisfaction and reported a significant difference
between digital scanning and conventional impressions (9.1 and 8.5 on a visual analog scale).

All authors agreed on the importance of the scanning protocol and compliance with
manufacturers’ recommendations, but only a few described the scanning path they followed. In
the Giménez et al studies,\textsuperscript{17,39,48} first scans were parallel to the arch to reproduce and connect the
bases of implant no.17 to implant no.27. Significant deviations were reported for the more
distant implant. Alikhasi et al\textsuperscript{37} began in the middle of the palate and registered the palatal
surfaces and then scanned the buccal and occlusal faces. Mangano et al\textsuperscript{33} adopted a zig-zag
scanning technique with the tip of the scanner drawing an arc movement from vestibular to
palatal and back. Cappare et al\textsuperscript{40} used a scanning procedure of half arches (occlusal view from
the more distal implant to the contralateral anterior implant) before a final merging with the
anterior implants used as references.

The influence of operator experience was thoroughly discussed. Giménez et al\textsuperscript{49}
specifically studied this parameter. With the Lava Cos, the operator experience significantly affected the accuracy of the impression. However, with the iTero and Cerec Bluecam, the results were affected by the operator without being necessarily related to operator experience because one inexperienced operator performed better than experienced operators.¹⁷,⁴⁸

The main limitations of the present study were the low number of clinical trials involving digital scanning for complete-arch implant-supported restorations. Results seemed promising, but longer follow-up is needed. However, the clinical validation of the framework fitting accuracy is difficult to ensure because radiographic evaluation and passivity sensation provide uncertain results.

The use of digital scanning for rehabilitation in edentulous patients will reach maturity when digital scanning is included in a complete digital workflow. The computer-aided design and computer-aided manufacture (CAD-CAM) subtractive process for complete denture fabrication is currently used and additive technology will be available soon. The next step should involve the development of vertical dimension recording and static and dynamic virtual simulation. Commercial solutions are available, but products are not yet integrated into everyday practice.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. Digital scanning of multiple implants in edentulous patients was as accurate as physical impressions of splinted copings in vitro.

2. The main parameters affecting precision were interimplant distance, body scan design, scanning pattern, and operator experience.

3. Clinical evidence is limited by the lack of means to assess the fit of the framework.
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FRANCE
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### TABLES

Table 1. Research strategy

| 1 | edentulous OR jaw, edentulous, partially/pathology OR jaw, edentulous/rehabilitation* OR full-arch OR dental Implants* OR dental prosthesis, Implant-Supported* OR dental implant OR *dental implantation, endosseous/methods |
| 2 | computer-aided Design* OR CAD/CAM OR dental impression Technique* OR dental models OR digital impression OR intra-oral scan OR computer-aided design/instrumentation OR computer-aided design/statistics OR numerical data* OR dental impression technique/statistics OR intraoral digitizer OR digital dentistry OR digital implant impressions OR full-arch implant impressions |
| 3 | dimensional measurement accuracy OR image processing, computer-assisted/instrumentation OR image processing, computer-assisted/statistics AND numerical data* OR image processing, computer-assisted/methods OR optical imaging/methods OR impression accuracy OR passive fit |
| 4 | in vitro techniques OR comparative study OR follow-up studies OR normalized controlled trial |

#1 AND #2 AND #3 AND #4
Table 2. Intra-oral scanners described in included studies

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Imaging Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIOS, 3Shape</td>
<td>Confocal microscopy and ultrafast optical scanning</td>
</tr>
<tr>
<td>Cerec Omnicam, Dentsply Sirona</td>
<td>Optical triangulation and confocal microscopy</td>
</tr>
<tr>
<td>True Definition, 3M</td>
<td>Active wavefront sampling 3D video technology</td>
</tr>
<tr>
<td>Lava Cos, 3M</td>
<td>Active wavefront sampling with structured light projection</td>
</tr>
<tr>
<td>iTero, iTero</td>
<td>Parallel confocal imaging technology</td>
</tr>
<tr>
<td>ZFX intrascan, Zimmer Biomet</td>
<td>Confocal microscopy and Moiré effect</td>
</tr>
<tr>
<td>Planscan, Planmeca</td>
<td>Optical coherence tomography and confocal microscopy</td>
</tr>
<tr>
<td>CS 3500, Carestream</td>
<td>Optical triangulation and generated individual images</td>
</tr>
<tr>
<td>CS 3600, Carestream</td>
<td>Active speed 3D video</td>
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</tbody>
</table>
Table 3. In vitro assessment of accuracy of digital scanning. S and NS indicate whether significant difference exists between digital scanning and conventional impressions in terms of accuracy. When different conventional impression techniques studied, outcomes for more accurate technique selected. Ext, external connection type; Int, internal connection type; True Definition.

<table>
<thead>
<tr>
<th>Number of implants</th>
<th>Max/mand</th>
<th>Angulation</th>
<th>Results</th>
<th>Control</th>
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<tr>
<td>5</td>
<td>-</td>
<td>Parallel implants</td>
<td><strong>Bias error value</strong> 14-21 µm</td>
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<td>5</td>
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<td>Parallel implants</td>
<td>Photogrammetry <strong>Location precision</strong>: 5.6 µm</td>
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<td><strong>Average measurement error</strong> 28.8 µm</td>
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<td><strong>Precision</strong> 55.2 µm</td>
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<td></td>
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<td>CS 3500</td>
<td>Trios 71.6 µm</td>
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<td>Zfx</td>
<td>Intrascan 103 µm</td>
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<td>112.4 µm</td>
<td>Planscan 253.4 µm</td>
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<td>204.2 µm</td>
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<td><strong>Precision</strong> 65.5 µm</td>
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<td>CS 3600</td>
<td>Omnicam 66.4 µm</td>
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<td>57.2 µm</td>
<td>Trios 3 67.2 µm</td>
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<td>31.5 µm</td>
<td>True Def 106.4 µm</td>
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<td>75.3 µm</td>
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<td>Distal implants 10° and 15°</td>
<td><strong>Bias error value</strong> 23.39 µm</td>
<td><strong>Implant</strong> 10° 5.79 µm</td>
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<td></td>
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<td>Nearest implant 15.27 µm</td>
<td>Nearest implant 9.16 µm</td>
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<td>Furthest implant 15° 29.02 µm</td>
<td>Furth impl 15° 12.52 µm</td>
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<tr>
<td>6</td>
<td>mand</td>
<td>Distance inter implant ranging from 5.70 to 10.28 mm and angles between 0.57 and 4.79°</td>
<td><strong>Trueness</strong> 112 µm</td>
<td><strong>Precision</strong> 66 µm</td>
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<td>Lava Cos 35 µm</td>
<td>True Definition 35 µm</td>
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<td>Trios 3 28 µm</td>
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<td></td>
<td>Omnicam 61 µm</td>
<td>59 µm</td>
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<th>Angulation</th>
<th>Results</th>
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<td>Amin S (2017)</td>
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<td>Distal implants 10° and 15°</td>
<td>Deviation (root mean square error)</td>
<td>Deviation (root mean square error)</td>
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<td>Omnicam 46.41 µm</td>
<td>167.93 µm S</td>
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<td>True Definition 19.32 µm</td>
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<td>Distal implants 45°</td>
<td>Trios Linear Angular</td>
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<td>Int straight 188 µm 0.585°</td>
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<td>tilted 162 µm 0.364°</td>
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<td>Ext straight 195 µm 0.587°</td>
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<td>tilted 165 µm 0.366°</td>
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<td>Ribeiro P (2018)</td>
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<td>Model 1: parallel implants</td>
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<td>Square of deviation</td>
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<td>Model 2: + 15° and -15°</td>
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<td>+ 30° and -30°</td>
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<td>Lava COS. Accuracy varied as a function of experience, operator and</td>
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<td>+ 30° and -30°</td>
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<td>Parallel implants</td>
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<td>Distance err Angle abs err</td>
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<td>True Definition 12 µm 0.257°</td>
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<td>Sheffield test 15 µm</td>
<td>Angle absolut error 0.536°</td>
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<td>Sheffield test 22 µm S</td>
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FIGURES

Figure 1. Flow diagram of study identification.
Identification
- Records identified through database searching: 233
- Additional records identified through other sources: 5

Records after duplicates removed: 208

Records screened: 70

Records excluded after title and language screen: 138

Records excluded after abstract screen: 38

Full-text articles assessed for eligibility: 32

12 Studies excluded:
- Edentulous jaws without implants
- Completely dentate arches
- Partially dentate arches
- Physical impressions only
- Case-report

Studies included in qualitative synthesis: 20