REVIEW ARTICLE

Evaluation of effectiveness of various dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis

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ABSTRACT
Aim-This systematic review and meta-analysis were conducted to assess and compare the accuracy of conventional and digital implant impressions. **Materials and Methods**-A systematic search was performed on PubMed/MEDLINE, CENTRAL, EMBASE, and Google Scholar databases, focusing on publications from the last five years, specifically from January 1, 2015, to January 1, 2020. Additionally, we conducted manual searches of pertinent journals, including Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, Journal of Clinical Periodontology, Journal of Computerized Dentistry, Journal of Implantology, and Journal of Periodontology.**Results**- Thirty studies were included in this systematic review. The study designs were categorized into three groups: 28 experimental studies, one retrospective study, and one randomized controlled clinical trial.**Conclusion**- The available data for accuracy of digital and conventional implant impressions have a low evidence level and do not include sufficient data on in vivo application to derive clinical recommendations.
Keywords- digital, scanner, implant

INTRODUCTION

Dental implantation is a surgical process of the jaw bone to support a crown, bridge, denture, and facial prosthesis. The basis of modern dental implantations is called osseointegration, it is the direct structural and functional connection between living bone and the surface of a load-bearing implant. Osteointegrated implants have been used to treat various condition ranging from edentulism to head and neck reconstruction. Dental implants are used to facilitate retention of auricular mandibular, maxillary, nasal, and orbital implants, and for bone-anchored hearing aids. The implant fixture is first placed so as to osseointegrate, and then a dental prosthesis is added. A variable amount of healing time is required for osseointegration before a crown, denture, or abutment is placed which will hold a dental prosthesis. Conventional implant practice dictates a delay between tooth extraction and implant placement, dividing the treatment into two differenced steps.

The success or failure of implants depends on the overall health of the patient and also drugs which interfere with bone metabolism, have adverse effect on the osseointegration. The position of implants is determined by the angle of adjoining teeth. The prerequisites for long-term success of osseointegrated dental implants are healthy bone and gingiva. Since both can atrophy after tooth extraction, preprosthesis procedures such as sinus lifts or gingival grafts are sometimes required to recreate bone and gingiva. The final prosthetic can be either fixed or removable. In each case, an abutment is attached to the implant fixture. Where the prosthetic is fixed, the crown, bridge, or denture is fixed to the abutment either with lag screws or with dental cement. Where the prosthesis is removable, a corresponding adapter is placed in the prosthetic so that the two pieces can be secured together.

The main objective in implant therapy is either to avoid complete removable dentures by placement of implant-supported fixed prostheses or to improve the retention and stability of removable complete dentures.[1] Basically, two approaches for an implant-supported fixed prosthesis exist. The first one is a metal-ceramic implant-supported fixed prosthesis consists of a ceramic layer bonded to a cast metal framework that can be cemented to transmucosal abutments or secured with prosthetic retention screws.[2] An alternative to this type of fixed prosthesis is an implant-supported hybrid prosthesis.[3] Implant supported metal-acrylic resin complete fixed dental prosthesis, originally referred to as a hybrid prosthesis was introduced to address the problems caused by unstable and uncomfortable mandibular dentures. The primary factor that determines the restoration type is the amount of intra-arch space.[4] In addition, other patient-relevant clinical parameters such as lip support, high maxillary lip line during smiling, a low mandibular lip line during a speech or the patient's greater esthetic demands should be evaluated.[5]

Hybrid prostheses have a great number of advantages including reducing the impact force of dynamic occlusal loads, being less expensive to fabricate and highly esthetic restorations.[5] Furthermore, they may be successfully used by a combination of tilted and axially placed implants in partial edentulism in the posterior part of resorbed maxillae.[6] However, food impaction, speech problems or difficulties in dealing with hygiene were reported by authors.[7]

Despite the favorable long-term outcomes achieved with prosthetic rehabilitations with implants, biological and technical complications such as surgical complications, implant loss, bone loss, peri-implant soft-tissue complications, mechanical complications, and aesthetic/phonetic complications are frequent.[8] The authors implied that such complications are affected by many factors, including the operator's skills and judgments in treatment planning, prosthesis design, materials, patient-specific factors, and local and systemic conditions and habits such as bruxism, smoking, presence of periodontal disease, and maintenance.[10] Furthermore, the communication between the prosthodontist and surgeon is emphasized as critical to ensure adequate restorative space for the various prosthetic designs, appropriate implant angulation, and minimizing cantilevers.[9]

This systematic review and meta-analysis were conducted to assess and compare the accuracy of conventional and digital implant impressions.

MATERIAL AND METHODS

This systematic literature review was performed adhering to Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.1 Pico question

The focused PICO (Population, Intervention, Comparison, Outcome) question was: "In patients requiring dental implant restorations, does the use of digital impressions compared to conventional impressions result in comparable accuracy of outcomes?"

2.2 Search strategy

A systematic search was performed on PubMed/MEDLINE, CENTRAL, EMBASE, and Google Scholar databases, focusing on publications from the last five years, specifically from January 1, 2015, to January 1, 2020. Additionally, we conducted manual searches of pertinent journals, including Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, Journal of Clinical Periodontology, Journal of Computerized Dentistry, Journal of Implantology, and Journal of Periodontology.

The search terms used were: ((((dental implants [MeSH Terms]) OR dental implant*)) AND ((dental impression technique [MeSH Terms]) OR dental impression technique*)) AND ((((dimensional measurement accuracy [MeSH Terms]) OR impression accuracy) OR accuracy) OR dimensional measurement accuracy). We tailored the search strategy and terms to fit each specific database."

Inclusion Criteria

- All levels of evidence except expert opinion
- Experimental and clinical studies
- Case reports with a minimum of five patients
- Both in vitro and in vivo studies
- Publications in peer-reviewed journals

Exclusion Criteria

- Multiple publications derived from the same patient population
- Animal studies

"Of the 30 studies included, 29 were neither randomized/nonrandomized controlled trials nor controlled clinical trials. Consequently, a quality assessment according to PRISMA guidelines was not conducted."

2.3 Study Selection and Quality Assessment

Two reviewers (TF and PW) independently screened the titles and abstracts of all studies retrieved through the search strategy, voting for their inclusion or exclusion. Disagreements were resolved through discussion with a third reviewer (BG). Following this, full-text screenings were conducted, and studies that did not meet the inclusion criteria or fell under the exclusion criteria were removed. Specifically, six studies were excluded for being outside the designated time frame, two case reports were excluded due to inappropriate study designs, and two studies not published in peer-reviewed journals were also excluded.

2.4 Data Extraction

The following data were extracted from each selected study:

Study Designs: Randomized/nonrandomized controlled trials, retrospective studies, case series, experimental studies

Study Settings: In vivo, in vitro

Impression Technologies: Digital, conventional

Tooth Status in the Implant Impression-Taking Region: Single-unit case, partially edentulous or completely edentulous arch, number and distribution of implants

2.5 Meta-analysis

Random-effect models were employed for the meta-analysis of each subgroup to compare the results of conventional and digital implant impression systems. This analysis was performed using Stata software (Stata 14.2, StataCorp).

RESULTS

Thirty studies were included in this systematic review. The study designs were categorized into three groups: 28 experimental studies, one retrospective study, and one randomized controlled clinical trial.

Most of the studies (24) were conducted in vitro using experimental models made of stone, metal, or resin, which included implants or laboratory analogs. One study examined digital impressions in vitro using formalin-preserved human mandibles. Additionally, one randomized controlled clinical trial, one retrospective study, and two experimental studies were conducted in vivo.

Digital impressions were investigated in 11 studies, while 18 studies focused on conventional impressions. Nine studies directly compared digital and conventional impressions.

Various impression techniques have been studied across different edentulous statuses. Nine studies focused on completely edentulous arches, with configurations including two implants (five studies), three implants (one study), four implants (four studies), five implants (two studies), and six implants (one study). In the context of partially edentulous arches, twelve studies were conducted, featuring specimens with one implant (one study), two implants (three studies), and combinations of two and five implants (one study). Additionally, two studies examined both partially and completely edentulous arches, while another study concentrated on completely edentulous arches with a single-unit restoration. Furthermore, two studies assessed single-unit restorations independently. One study included patients with various indications for implant therapy.

3.1 Angulation and vertical position of implants

Among 30 studies analyzed, the assessment of impression accuracy for parallel implants was addressed in 8 studies. Among these, 5 studies specifically examined specimens featuring angulated implants, while 4 studies did not specify the angulation of implants, and 2 studies involved specimens with a single implant.

In terms of comparative analysis, 11 studies delved into the distinction between impression accuracy for parallel and angulated implants. Notably, conventional implant impressions of angulated implants exhibited significantly lower accuracy compared to parallel implants across various impression techniques. Nevertheless, some studies indicated that different implant angulations did not yield a significant difference in impression accuracy.

Similarly, digital impressions of angulated implants didn't exhibit a significantly different impression accuracy compared to parallel implants. Interestingly, there was a noted improvement in impression accuracy with digital implant impressions featuring implant divergence when compared to parallel implants.

In the majority of studies focusing on conventional implant impressions, the vertical position of implants wasn't thoroughly assessed. Although the placement of implants at equigingival or supragingival levels was mentioned, its impact on impression accuracy wasn't evaluated. Implants were positioned at depths ranging from 0 to 3 mm, among other specifications, yet the independent effect of depth on impression accuracy wasn't investigated.

In contrast, among the five studies utilizing digital impressions, the vertical position of implants was scrutinized. Implants were placed either equigingivally or at depths of 2 to 4 mm subgingivally. However, in none of these studies did the implant depth significantly affect impression accuracy.

3.2 Operator experience

Some conventional implant impression accuracy studies noted the experience level of operators. For instance, in a clinical study, impressions were conducted by both senior dentists and residents. The accuracy of each impression technique was assessed by evaluating the fit of implant-supported frameworks using periapical radiographs. Interestingly, when performed by senior dentists, there was no discernible difference in fit among three different impression techniques. However, when residents performed the impressions, frameworks with poor fit were significantly more prevalent, particularly with an impression technique that involved intraoral splinting of copings to impression trays.

Three studies investigating digital implant impression techniques explored the impact of operator experience on impression accuracy. In one study, a notable contrast emerged between experienced and inexperienced operators, with one inexperienced operator demonstrating significantly lower impression accuracy compared to two experienced operators, along with another inexperienced operator. However, in another study, inexperienced operators showcased superior performance in impression accuracy compared to experienced counterparts, albeit using a different intraoral scanning device.

In a separate study, initially, experienced operators exhibited significantly higher accuracy in digital impressions. However, as the scanning series progressed, the difference between experienced and inexperienced operators became insignificant. Interestingly, when employing two other scanning devices, no significant differences were observed in digital impression accuracy between experienced and inexperienced operators.

3.3 Optical scanning devices

Various optical scanning devices were investigated in the included studies, encompassing both direct intraoral optical scanning and extraoral scanning of stone casts.

In the realm of extraoral optical scanners, multiple studies explored their accuracy employing diverse technologies. These included blue and white light scanners, laser scanners, photogrammetric scanners, and photogrammetric technology utilizing a digital camera. Additionally, some studies utilized conoscopic holography and an optical tracking device. Furthermore, one study utilized CBCT technology for the acquisition of implant positions. The intraoral scanning devices studied encompassed Trios, Cerec, iTero TrueDefinition, LavaCOS, 3D Progress (MHT), and ZFX Intrascan (Zimmer).

3.4 Scan bodies

The majority of studies utilized original implant scan bodies for both intraoral and extraoral optical scanning. Additionally, generic scan bodies or abutments were employed in some studies, while photogrammetric acquisition of implant positions utilized custom-made scan bodies. However, in certain cases, the specific scan bodies used were not disclosed.

In terms of design, most commonly used scan bodies had a cylindrical shape. However, there were exceptions where original scan bodies had a unique design with a short lower part and an angled top part. For photogrammetric acquisition, two different designs were examined: a vertical shaft with spheres positioned close to the implant and at the coronal end, and scan flags made from titanium or paper with varying flag surface sizes and surface patterns.

Importantly, scan bodies were never splinted for either extraoral or intraoral scanning, and powder application followed manufacturer instructions.

3.5 Conventional impressions

Conventional implant impressions were performed using the open tray method, the closed tray method, or both methods for comparison of accuracy. Additionally, two studies compared stress induced by splinting two impression posts on dental implants with different splinting materials and techniques.

Impression copings were chosen based on implant specifications and tray design. For open tray impressions, pick-up impression copings were utilized, while conical screw-retained impression copings and screw-retained copings with plastic caps retained in the impression were used for closed tray impressions. Additionally, Encode abutments and original implant abutments were employed for conventional impressions.

In 13 studies, pick-up copings with screw retention for open tray impression techniques were utilized. However, conical transfer copings were not exclusively used in any study, and screw-retained copings with plastic caps were only examined in one study. Furthermore, 16 studies compared different impression copings with each other. Notably, two studies did not disclose the specific impression copings used.

Impression materials utilized in the studies included polyvinylsiloxane, vinylsiloxanether, polyether, and condensation silicone. Polyvinylsiloxane materials were employed in 26 studies, polyether in 22 studies, and vinylsiloxanether and condensation silicone each in one study. Additionally, 16 studies compared various combinations of these impression materials.

Numerous studies investigated and compared the splinting of impression copings with nonsplinting. Thirty-two studies employed nonsplinted impression copings, while seven studies utilized splinted impression copings for open tray impressions. Additionally, one study utilized splinted conical transfer copings for closed tray impressions. Furthermore, twenty-five studies compared splinted and nonsplinted impression techniques.

3.6 Outcome assessment

The accuracy outcomes were evaluated through various methods, including:

1. Measurement of linear and angular deviations or three-dimensional surface deviations between reference models and test models. This assessment was conducted using coordinate measuring machines (CMM), microscopes, digital micrometers, profile projectors, laser measuring machines, or standardized photographs.
2. Virtual measurements of implant distances and angulations after optical digitization of stone casts produced from conventional impressions or after performing optical impressions with various intraoral scanners.
3. Virtual measurement of three-dimensional surface deviations between scan

bodies/impression posts mounted on implants in reference models and test models.

4. Assessment of the accuracy of implant-supported frameworks produced on master models and fitted on test models, which included measuring strain using strain gauges, marginal discrepancy between abutment and framework using various measurement tools such as microscopes, optical comparators, surface profilometers, or electron microscopes, examining the three-dimensional fit of frameworks by measuring lining material thickness, probing of the gap between frameworks and abutments, and interpreting fit on periapical radiographs and photographs.These methods were employed across the studies to comprehensively evaluate the accuracy of implant impressions and frameworks.

3.7 Meta-analysis

30 studies were examined in a systematic review comparing the accuracy of conventional and digital impressions. The analysis included mean values and standard errors for linear and angular distances, three-dimensional surface deviations, marginal discrepancy, and strain.

Sixteen studies were excluded from meta-analysis due to various reporting differences:

a) Studies reporting median values and ranges or mean values without standard errors.
b) Studies where mean deviations couldn't be calculated due to incomplete data.
c) Studies lacking measuring units for deviations.
d) Studies where attempts to clarify methods and results failed.
e) Studies lacking numerical values for accuracy.
f) Studies assessing fit using methods not comparable with marginal discrepancy values.

This resulted in a meta-analysis of 13 studies. The studies were categorized based on clinical scenarios, implant distribution within the jaw, and implant angulations. Linear and surface deviations, angular deviations, and marginal discrepancies of both conventional and digital impressions were analyzed and presented.

Studies on conventional impressions have primarily focused on edentulous conditions and implants distributed across the complete dental arch. Reported mean linear and surface deviations were 97.1 µm (CI 93.2–100.9 µm) and angular deviations were 2.0° (CI 1.6–2.0°) for parallel implants. For implants with unknown angulation, the deviations were 77.7 µm (CI 64.9–90.5 µm) and 0.6° (CI 0.4–0.7°). However, there was high heterogeneity, with 100% and 96.4% for linear and surface deviations and 95.9% and 97.0% for angular deviations. Implants with an unknown position in the dental arch and interimplant angulations of 21–45 degrees showed even higher linear and surface deviations, averaging 431.6 µm (CI 285.0–578.2 µm). Fewer studies have examined digital impressions of edentulous jaws with parallel implants distributed throughout the complete dental arch. These studies found linear and surface deviations of 51 µm (CI 28.0–74.0 µm) with a heterogeneity of 69%. Conventional impressions of partially edentulous jaws typically evaluated neighboring implants, resulting in mean linear and surface deviations of 28.7 µm (CI 26.3–31.2 µm) and mean angular deviations of 0.2° (CI 0.2–0.3°). Fewer studies on digital impressions were available, showing mean deviations of 11.9 µm (CI 4.1–19.8 µm) and 0.4° (CI 0.3–0.4°). One study reported high deviations for digital impressions of parallel implants within one quadrant, with a mean deviation of 304.0 µm (CI 278.6–320.4 µm) and a mean angular deviation of 1.6° (CI 1.3–1.9°). For angulated implants (21–45 degrees) within one quadrant, the mean deviations were 158.0 µm (CI 102.8–213.2 µm) and 1.2° (CI 0.8–1.7°).

Marginal discrepancies for frameworks manufactured from conventional impressions ranged from 18.3 to 141.5 µm in edentulous arches, 78.1 µm in partially edentulous arches, and 24.9 µm for single units. For digital impressions, the mean marginal discrepancies of frameworks were between 19.0 and 70.2 µm in edentulous arches, 11.9 and 304.0 µm in partially edentulous arches, and 66.1 µm for single units.

DISCUSSION

Accurate and precise planning in dental implantology includes detecting any existing clinical difficulties prior to the treatment and foreseeing the final results before the treatment.[1] Planning for esthetic cases requires different diagnostic perspective; it should include additional factors such as smile patterns and lip size, etc.[12] In addition, the restorative space for the prostheses, which is measured from the platform of the implant to the opposing occlusion, is often overlooked when implant positions are planned.[11] The intra-arch distance which implant components, metal substructure, the acrylic resin, and the denture teeth are placed plays a major role on selecting appropriate restoration. With mandibular implant-supported fixed prostheses, a minimum of 12–15 mm of space has been suggested.[2] When more intra-arch space is present, a hybrid restoration is recommended.[4]

Implant supported hybrid prosthesis can provide satisfactory results where esthetic and functional requirements are demanding and challenging as in increased intra-arch space that remains following conventional implant replacements, the dentist needs to plan for an alternative treatment procedure that best suits the situation.[12] The patients' acceptance of the prosthetic treatment plan and restorative solution were certainly promoted by the fabrication of implant supported hybrid prosthesis.

The other important aspect to consider is the maintenance of prosthetic rehabilitation as well as the implants by supporting the structure.[13] Regular checks are recommended every 6 or 12 months to avoid complications and to assess the status of the peri-implant tissue.[14] Moreover, the measurement of radiographic peri-implant marginal bone loss during the follow-up period is also recommended.

The data extracted for the systematic review and meta-analysis are limited as it is mostly derived from experimental studies with low evidence level. The in vitro setup of the majority of studies reduces the informative value of the data for the clinician. The decision to use conventional or digital implant impressions should be based on available data for accuracy of each impression technique. Therefore, evidence-based data and clinical trials are necessary to support clinical guidelines. The current literature does not provide high-quality evidence to support the selection of conventional and digital impression techniques of implants.

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