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REVIEW ARTICLE

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Accuracy of digital implant impressions in clinical studies: A systematic review

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Abstract

Objectives: The use of intraoral scanners (IOSs) for digital implant impressions in daily clinical practice is increasing. However, no structured literature review on the accuracy of digital implant impressions in clinical studies has been described to date. Therefore, this systematic review aimed to answer the PICO question: Which accuracy is described for digital implant impressions in clinical studies?

Material and Methods: An electronic database search was conducted in December 2021 using MeSH terms and free-text search. English-language studies addressing the accuracy of digital implant impressions in clinical studies involving at least 10 patients were included. All clinical indications were considered.

Results: Eight publications between 2014 and 2021 matched the review criteria. However, the study designs showed considerable differences. The number of implants within the studies ranged from 1 to 6, and the number of patients ranged from 10 to 39. The oldest study (2014) revealed the highest deviation for linear distances at 1000 ± 650 μm, whereas the other studies reported data in the range of 360 ± 46 μm to 40 ± 20 μm. In one study, no numerical data were reported and all studies compared digital and conventional implant impressions.

Conclusions: The number of clinical studies on the accuracy of digital implant impressions is low. Thus, the impact of different factors, such as the scanpath or scanbody, could not be identified. However, the accuracy of recent IOSs for digital implant impressions in patients was shown to be clinically acceptable. Nevertheless, the transfer error still needs to be considered when fabricating implant-supported restorations.

KEYWORDS
clinical study, dental implants, dental impression technique, digital dentistry, dimensional measurement accuracy, intraoral scanner

1 | INTRODUCTION

Currently, implant-supported prosthodontic restorations are a commonly accepted treatment option for functional and aesthetic rehabilitation of partially and completely edentulous patients (Pjetursson et al., 2012; Srinivasan et al., 2017). In this context, the use of intraoral scanners (IOSs) for digital implant impressions is continuously increasing (Blatz & Conejo, 2019; Michelinakis et al., 2021).

However, the advent of digitization has become apparent at all the steps of a combined implant-prosthetic workflow (Joda et al., 2015), which begins with planning of the implant position (Kernen et al., 2020), followed by digital implant impression taking with IOS (Abduo & Elseyoufi, 2018), and ending with the manufacturing of dental prosthesis with computer-aided design/computer-aided manufacturing (CAD/CAM) technology (Merrill et al., 2021). For all steps, a correct three-dimensional transfer of the intraoral structures to a gypsum or virtual model is necessary. This is the only possible way to ensure that the extraoral model represents the intraoral situation with maximum accuracy. Moreover, the fabrication of implant-supported prosthodontic restorations needs a high degree of accuracy (Schmidt et al., 2019; Schmidt et al., 2021b; Schmidt, Rein, et al., 2021). While restoring natural teeth, minor inaccuracies can be compensated by their inherent mobility, which is not possible in case of implants as they have a 10-fold lower inherent mobility than natural teeth (Chang et al., 2012; Winter, Klein, & Karl, 2013a,b). Thus, implant impressions play a key role in achieving a passive fit of implant-supported prosthodontic restorations (Farronato et al., 2021), as the prosthetic restoration is fabricated on the basis of the digital or conventional models. However, passive fit can only be guaranteed if prosthodontic restoration can be inserted without any tension, which requires an accurate model (Abu Ghofa & Onoral, 2021).

To date, no intraoral implant impression allows a three-dimensional transfer to a model without any error. Therefore, these inaccuracies are compensated by intraoral bonding of a tertiary structure in prosthodontic restorations (Weigel et al., 1994). An exact range of tolerance regarding the necessary accuracy of implant impressions has not yet been defined, and the opinions about the allowable range of accuracy differ. While Brånemark (Brånemark, 1983) demanded a gap between the framework and abutment of 10 μm or less, Jemt (Jemt, 1991) described a gap of less than 150 μm as acceptable. This problem is not limited to digital implant impressions but is also well known for conventional implant impression taking.

Several conventional methods have been presented with different impression methods (open and closed) and impression materials (polyether, polyvinylsiloxane) (Alikhasi et al., 2015; Daoudi, Setchell, & Searson, 2001, 2003; Tabesh et al., 2018; Vigolo et al., 2014). The influence of different implants and their angulation were investigated (Rutkunas et al., 2012; Schmidt et al., 2018; Sorrentino et al., 2010; Teo et al., 2014; Vojdani et al., 2015). In addition, other possible influencing factors were described (number of remaining tooth implant depth, implant number, and the use of splints during impression taking) (Abduo & Palamara, 2021; Menini et al., 2018; Papaspyridakos et al., 2014; Rutkunas et al., 2017; Siadat et al., 2016). Numerous reviews suggest that the open direct impression technique and blocked impressions provide more accurate results with an increasing number of implants. Furthermore, tilted implants showed a higher deviation in accuracy (Baig, 2014a,b; Kim et al., 2015; Lee et al., 2008; Moreira et al., 2015; Papaspyridakos et al., 2014).

Even if conventional implant impression taking can produce good to excellent results, errors can still occur. Errors inherent in the system, such as the shrinkage of impression materials or plaster expansion, are unavoidable, and the increasing possibilities of digital impressions using IOS and CAD/CAM-produced dental restorations have brought them more to the foreground. However, even though the digital system should help avoid errors in the conventional process chain, errors can also occur in the digital workflow. The selected scanpath (Ender & Mehl, 2013; Müller et al., 2016), the user (Rutkunas et al., 2017), a lack of calibration (Rehmann et al., 2017), the software or hardware version (Haddadi et al., 2018; Schmidt, Schlenz, et al., 2021; Shim et al., 2015; Vag et al., 2021), and scanbody used (Schmidt et al., 2019; Schmidt et al., 2021b) are possible factors that influence the accuracy.

In all accuracy studies, it is first necessary to precisely define the accuracy of the transfer, which comprises trueness and precision that are described in detail in ISO 5725-1:1994. Trueness describes the closeness of the measurement result to the original, and precision involves its standard deviation (International Organization for Standardization, 1994). The problem with all accuracy measurements is the missing information about the reference data of the patient. Therefore, recent investigations only compared the reproducibility between indirect and direct digitization and not the accuracy meaning trueness and precision (Ender et al., 2016; Ender et al., 2016).

Comparatively, there are more studies involving the digital impression taking of natural teeth. It has been found that it is currently possible to achieve the accuracy of conventional impressions with the help of IOS or obtain even more accurate results with digital impressions (Ahlholm et al., 2018; Aswani et al., 2020; Chochlidakis et al., 2016; Kihara et al., 2020; Schmidt, Klussmann, et al., 2020; Ting-Shu & Jian, 2015). In contrast, although there is some literature on digital implant impressions, no single study has focused exclusively on clinical studies. However, clinically relevant studies, especially those associated with digital impressions, are of enormous importance, as the results from *in vitro* studies are difficult to apply in clinical applications. In particular, the presence of saliva and patient movements during digital impression acquisition can lead to major inaccuracies. Therefore, this review aimed to collect the currently available literature regarding the accuracy of digital implant impressions in clinical studies.

2 | MATERIALS AND METHODS

This review was performed in accordance with the guidelines of the Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) and the Population, Intervention, Comparison, Outcomes, and Study (PICOS) criteria (Moher et al., 2015).

2.1 | Specific question

Which accuracy is described for digital implant impressions in clinical studies?

TABLE 1 MeSH and free-text terms used in the electronic search strategy (updated 2021-12-08)

Search terms	Number of records returned
MeSH terms	
(Dental impression technique[MeSH]) AND (Dimensional measurement accuracy[MeSH])	30
(Dental impression technique[MeSH]) AND (Dental implants[MeSH])	580
(Dental impression materials[MeSH]) AND (Dental implants[MeSH])	257
(Dental implant abutment design[MeSH]) AND (Dental impression technique[MeSH])	73
Free text	
Implant AND impression	2539
Implant AND intraoral scanner	286
Implant position AND digital	1155
Implant impression AND accuracy	507
Implant impression AND trueness	62
Implant impression AND precision	259
Implant impression AND digital	478
Intraoral scanner AND scan body	29

2.2 | Eligibility criteria

For inclusion and exclusion of studies, PICOS criteria were used.

- Population: Partial or completely edentulous patients;
- Intervention: Single-unit or multi-unit implant impressions with common IOSs and scanbodies;
- Comparison: Accuracy between digital implant impression and reference model/reference dataset;
- Outcomes: Measurement of accuracy (linear distances and if available angulation); and
- Study design: Clinical studies.

2.3 | Inclusion criteria

In this systematic review, the following inclusion criteria were defined:

- Clinical studies (prospective or retrospective cohort studies, randomized controlled trials);
- Articles in English language;
- Cohort studies including at least 10 patients; and
- Investigations reporting on digital and conventional implant impressions.

2.4 | Exclusion criteria

- Expert opinions;
- Case reports;
- Clinical or technical reports;
- Review or incomplete articles;
- Animal studies;
- Insufficient information on defined outcome criteria;
- Studies dealing with the deviation of restorative materials;
- Multiple publications on the same patient population; and
- Data older than 20 years.

2.5 | Search strategy and data collection

The literature search was conducted electronically on the following databases: MEDLINE/PubMed, PubMed Central, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and Excerpta Medica Database (EMBASE). Only English-language publications were included in this study. The latest search was conducted on December 08, 2021. A detailed search strategy was performed using MeSH terms and free-text searches, as listed in Table 1. Two trained reviewers (A.S. and M.A.S.) screened the titles and abstracts of all publications, and duplicates were identified and deleted. In case of incomplete information within the abstract, full texts were examined. In addition, previous review articles and reference lists of previously identified articles were searched for other potentially relevant publications (additional "freehand search"). The full texts of the selected outcomes were then examined. Based on the inclusion and exclusion criteria, the studies were included in the review. The data were further subdivided into arch type, sample size, number of implants, implant angulation and depth, implant system, IOS and software, scanbody, conventional impression method and material, parameters evaluated, measurement method, reference system used, and accuracy evaluation results. Discrepancies regarding the recording of datasets, titles, abstracts, or full texts, including the contents,

TABLE 2 Setup and results of clinical studies on the accuracy of digital implant impressions

Article (year)	Arch type/sample size	Number of implants	Implant angulation	Implant depth	Implant system	Scanner/software
Andriessen et al. (2014)	Mandibular/25	2	Not specified	Not specified	Straumann Standard SLA-active, Regular Neck 4.1/12 mm; Straumann, Freiburg, Germany	iTero; Cadent Inc. (Carlstadt, NY, USA)/3.5.0
Rhee et al. (2015)	Mandibular/24	1	Not specified	Not specified	Not specified	Trios mono cart (3Shape, Copenhagen, Denmark)/not specified
Alsharbaty et al. (2019)	Mandibular/36	2	<20°	No more than 3-mm gingival depth	Implantium internal connection 3.8/4.8 mm; Dentium, Seoul, South Korea	TRIOS 3Shape IOS; (3Shape, Copenhagen, Denmark)/not specified
Gedrimiene et al. (2019)	Mandibular/24	2	Not specified	Not specified	AnyOne (Megagen, Daegu, Korea)	TRIOS 3Shape IOS; (3Shape, Copenhagen, Denmark)/1.3.4.2
Jiang et al. (2019)	Maxilla and mandibular/34	2	Not specified	Not specified	Camlog Screw-Line Implant (Camlog Biotechnologies AG, Basel, Switzerland)	TRIOS 3Shape IOS; (3Shape, Copenhagen, Denmark)/not specified

Scanbody	Conventional impression method/material	Parameters evaluated	Measurement method	Reference system used	Accuracy evaluation results (µm/°)
	Not specified	Linear distance, angulation error, optical irregularity	Three-dimensional measurement	Intraoral scanbody	Linear deviation: 1 ± 650 µm; angle deviation: 0.123 ± 9.563°
	Dual-arch/full-arch impression reposition technique/polyvinyl siloxane	Linear distance	Three-dimensional measurement/ superimposition	Intraoral scanbody	n/a
Dentium scanbody (Regular scanbody 4.789 × 10 mm; Doowon International Dental, Seoul, South Korea)	Pick-up impression and reposition technique/ polyvinyl siloxane, Panasil Soft Putty and Light Body (Kettenbach, Eschenburg, Germany)	Linear distance, angulation displacement, distance deviation	Three-dimensional measurement	Intraoral scanbody	Linear displacement 210 ± 30 µm (transfer); 160 ± 25 µm (pick-up); 360 ± 46 µm (digital); angle deviation: 2.28 ± 0.47° (transfer); 2.01 ± 0.33° (pick-up); 6.77 ± 0.91° (digital); distance deviation: 110 ± 20 µm (transfer); 90 ± 20 µm (pick-up); 220 ± 30 µm (digital)
3Shape Scanbody (3Shape, Copenhagen, Denmark)	Pick-up impression with splinted transfers/ polyvinyl siloxane; Express (3M, Maplewood, MN, USA)	Linear distance, angulation displacement, rotational displacement, vertical shift	Three-dimensional measurement	Intraoral scanbody	Linear difference between conventional and digital: 70.8 ± 59 µm; angulational displacement between conventional and digital: 0.37 ± 0.3°; rotational displacement between conventional and digital: 2.0 ± 1.37°; vertical shift: 82.2 ± 61.7 µm
Not specified	Not specified	Superimposition between conventional and digital impression	Best-fit algorithm	Intraoral scanbody	Superimposition between digital and conventional impression 27.43 ± 13.47 µm

(Continues)

TABLE 2 (Continued)

Article (year)	Arch type/sample size	Number of implants	Implant angulation	Implant depth	Implant system	Scanner/software
Chochlidakis et al. (2020)	Maxilla/16	6	Not specified	Bone level	BLT Roxolid SLActive (Straumann AG, Basel, Switzerland)	True definition (3M, St Paul, MN)/not specified
Rutkunas et al. (2020)	Maxilla and mandibular/27	2	Not specified	Not specified	AnyOne (Megagen, Daegu, Korea)	TRIOS 3Shape IOS; (3Shape, Copenhagen, Denmark)/1.3.3.1
Schmidt et al. (2021)	Maxilla and mandibular/39	3	<15°	Not specified	ProActive Straight (Neoss, Cologne, Germany); Narrow Crossfit and Regular Crossfit Bone Level (Straumann, Basel, Switzerland)	Trios 3 Pod (3Shape, Copenhagen, Denmark)/1.9.1.2, normal scanning speed

were discussed so that a consensus could be obtained between all authors.

2.6 | Quality assessment

The PRISMA guidelines were followed as a recommendation for preferred reporting contents (Appendix S1). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria (Vandenbroucke et al., 2007) were used as an assistance to report the research results available in the literature. The assessment of the risk of bias of each study was assessed using the "Rob 2 tool," an instrument for assessing the risk of bias in randomized controlled trials (Sterne et al., 2019). This tool includes several algorithms that assess a potential risk of BIAS based on several questions in individual domains. These domains are organized as follows: bias arising from the randomization process (D1), bias due to deviations from intended intervention (D2), bias due to missing outcome data (D3), bias in measurement of the outcome (D4), and bias in the selection of the reported result (D5). Through the algorithm's specific assignments to each possible combination of answers to the questions (including "no information" responses), the risk of bias was classified. The possible sum of the individual questions resulted in the classifications of low risk of bias, some concern, or high risk of bias (Sterne et al., 2019). The web application "robvis" was used to graphically display the risk of bias assessment of each investigation (Figure 2).

3 | RESULTS

3.1 | Included studies

The first search resulted in 6255 records, and after deleting duplicates, the total number of records was 3967. After title screening, the remaining number of results was 974. After reviewing the abstracts, 54 studies were included in the review. After reviewing the full texts of the 54 records, eight studies were ultimately selected for review based on the previously defined inclusion and exclusion criteria (Table 2). All of them were cohort studies. The study selection process is illustrated in Figure 1. Most of the

Scanbody	Conventional impression method/material	Parameters evaluated	Measurement method	Reference system used	Accuracy evaluation results (µm/°)
CARES Mono scanbodies (Straumann AG, Basel, Switzerland)	Pick- up impression/ polyvinyl siloxane Imprint (3M, St. Paul, MN, USA)	Superimposition between conventional and digital impression	Best-fit algorithm	Reference spheres	Superimposition between digital and conventional impression 162 ± 77 µm
AnyOne (MegaGen, Montagnola, Switzerland)	Pick-up impression with splinted transfers/ polyvinyl siloxane; Express (3M, Maplewood, MN, USA)	Distance between center points, angulation, rotation, vertical shift	Three-dimensional measurement	Intraoral scanbody	Linear difference between conventional and digital: 73.7 ± 75 µm; angulational displacement between conventional and digital: 0.42 ± 0.3°; rotational displacement between conventional and digital: 0.72 ± 0.55°; vertical shift: 98.9 ± 96.33 µm
N-series, Neo-series (NT-Trading, Karlsruhe, Germany)	Pick-up impression/ polyether; Impregum Penta (3M ESPE, Seefeld, Germany)	Distance between center points	Three-dimensional measurement	External reference key	Linear distance: upper jaw conventional 45 ± 35 µm, digital 40 ± 29 µm; lower jaw conventional 46 ± 27 µm, digital 79 ± 50 µm

results were *in vitro* studies and were therefore not included in this review.

The risk of bias is graphically displayed in Figure 2. Overall, some risk of bias was found in all included studies. This was mainly due to missing data with regard to the randomization process. Furthermore, it remained unclear in some cases whether the data were available to the respective participants in advance, as often no information was provided about this within the studies. With regard to the measurements, a possible risk of bias due to the lack of information on the deviations could only be found in one study. Moreover, in some studies it was unclear which exact analysis method was used.

The number of cases in the studies included in this review ranged from 10 (Schmidt, Billig, et al., 2020) to 39 (Schmidt, Rein, et al., 2021), whereas the number of implants ranged from 1 (Rhee et al., 2015) to 6 (Chochlidakis et al., 2020); only a few studies reported the maximum implant angulation (Alsharbaty et al., 2019; Schmidt, Rein, et al., 2021) and the depth (Alsharbaty et al., 2019) of implant placement. Different implant manufacturers were included in this review, whereas only three IOS manufacturers were a part of this review. The Trios IOS was used in five studies (Alsharbaty et al., 2019; Gedrimiene et al., 2019; Jiang et al., 2019; Rhee et al., 2015; Rutkunas et al., 2020; Schmidt, Billig, et al., 2020; Schmidt, Rein, et al., 2021), whereas the iTero IOS (Andriessen et al., 2014) and True Definition IOS (Chochlidakis et al., 2020) were used in only one study. Different intraoral scanbodies were used for the digital impressions, which was also the case with conventional impressions. The application ranged from closed impressions (reposition technique) to open impressions (pick-up technique) with or without additional blocked impression posts. Accordingly, polyether materials or vinylpolysiloxane-based materials from different manufacturers were used for conventional impression taking. The parameters evaluated typically used linear distances between individual scanbodies or superimposition. The most frequently used references were existing scanbodies screwed intraorally (Alsharbaty et al., 2019; Andriessen et al., 2014; Gedrimiene et al., 2019; Jiang et al., 2019; Rhee et al., 2015; Rutkunas et al., 2020). Only one study used reference spheres (Chochlidakis et al., 2020), while one study used external reference structures.

Figure 3 graphically shows the results of the studies included in the review in terms of linear deviations in accuracy. It is clearly

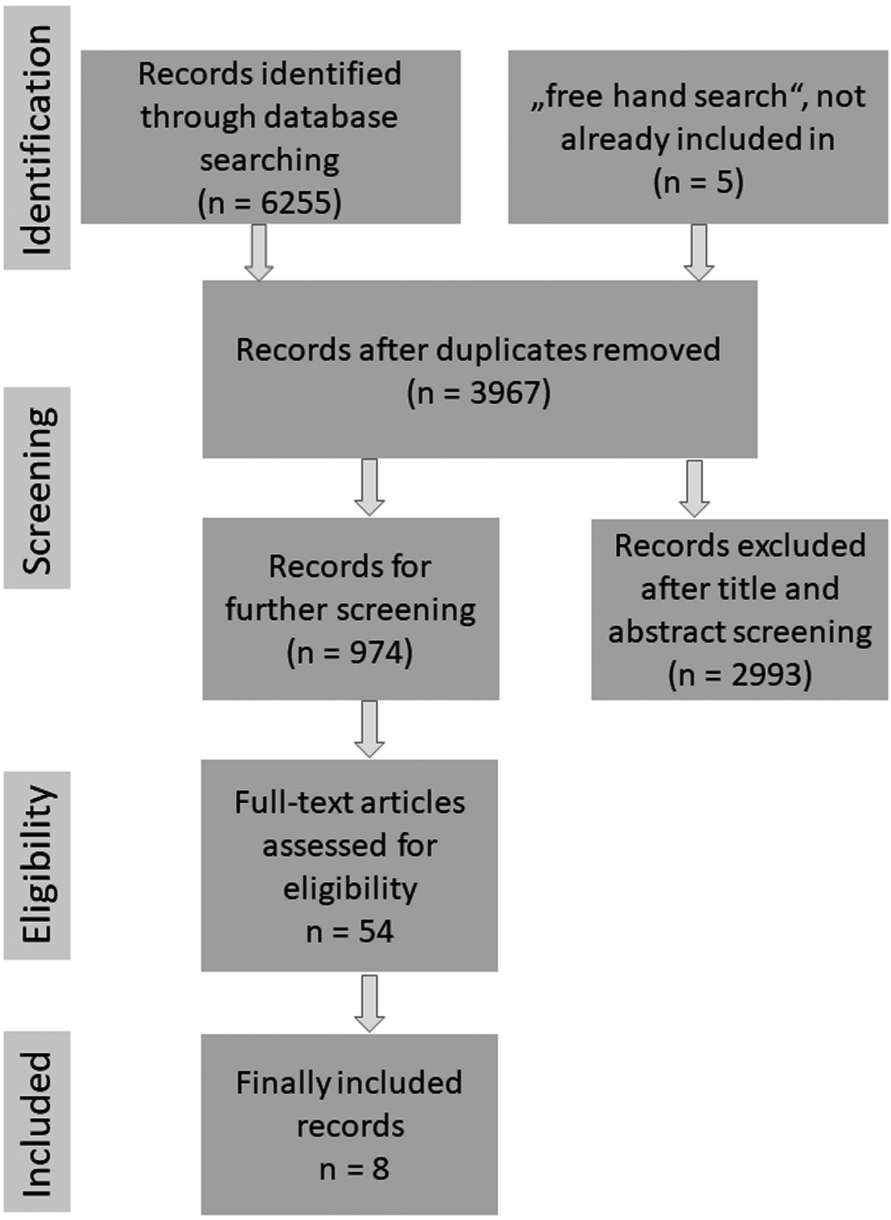

FIGURE 1 Study selection process based on the PRISMA flow diagram

noticeable that the highest deviations (>500 μm) occurred in the oldest study by Andriessen et al. from 2014. In contrast, the deviations in the more recent studies were significantly lower (<85 μm). Only the studies by Alshabarty et al. and Chochlidiakis et al. also showed higher deviations (>160 μm).

4 | DISCUSSION

This systematic review aimed to collect the currently available literature regarding the accuracy of digital implant impressions in clinical studies. In recent years, implant-supported prosthodontic treatments have significantly increased in daily practice (Patzelt, Bahat, et al., 2014). Although conventional impression techniques for implant dentistry were commonly used in the past, the use of IOS for digital implant impression taking has steadily increased with time.

As a limitation of the present review, most studies in this field are solely laboratory-based; thus, the number of clinical studies is limited. However, eight *in vivo* studies were identified for inclusion in this review. If the conventional impression is defined as the gold standard and the impression using an IOS is tested against it, the sensitivity and specificity would typically have to be specified. However, this is not possible as these are typically not described within the included studies on the accuracy of digital impressions. The highest deviations were found in a study by Andriessen et al. (Andriessen et al., 2014). This is the oldest available study, and it may be hypothesized that the high accuracies are related to the oldest software version of the iTero scanner used. Similar results have been reported in *in vitro* studies from the same time (Nedelcu & Persson, 2014; Patzelt, Bishti, et al., 2014). Newer hardware devices or software versions of the scanners can lead to more accurate results (Schmidt, Schlenz, et al., 2021). The findings of another

FIGURE 2 Graphical display of the risk of bias using "robvis"

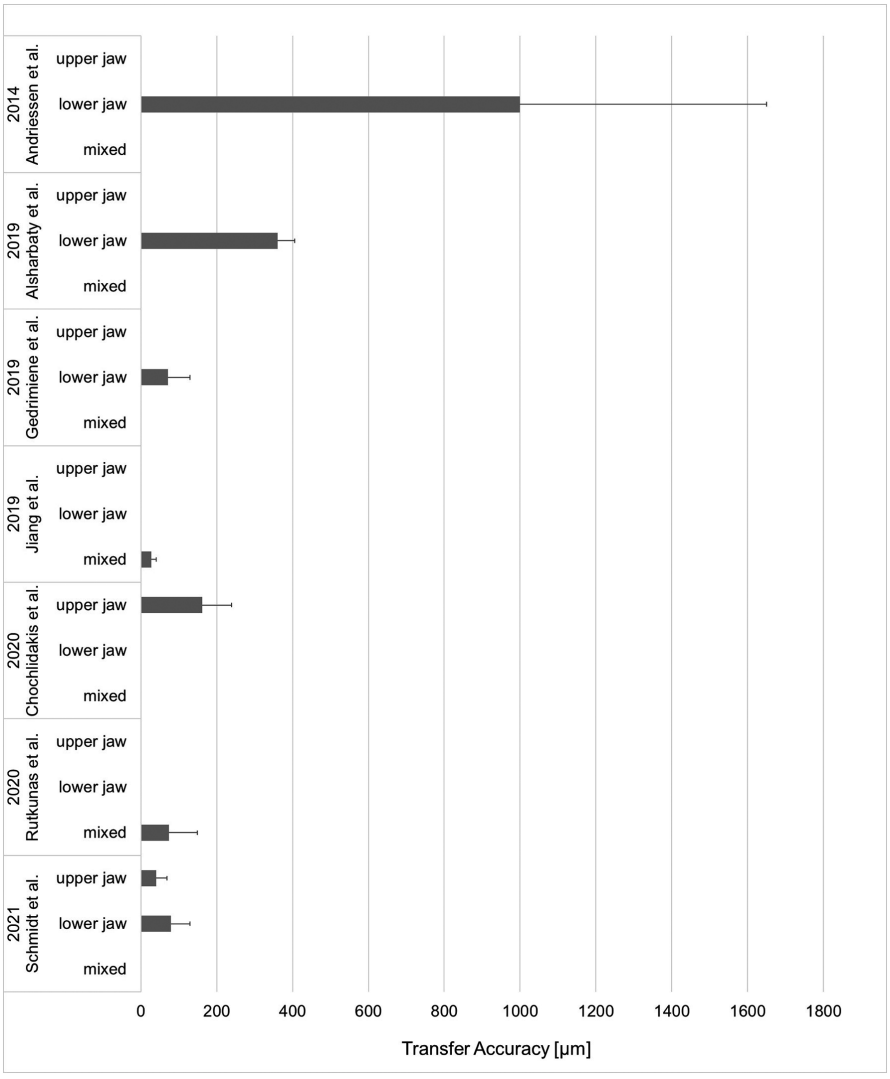

FIGURE 3 Results of linear deviations in terms of accuracy of the included studies

study also showed high deviations (Alsharbaty et al., 2019), and an older version of the TRIOS IOS was used in this study. This IOS was used most frequently in all the included studies in the present review. IOS, iTero, and TRIOS IOS work according to the principle of confocal laser scanning microscopy. It cannot be precluded that the higher deviations are also due to the older hardware generation in combination with the older software versions of the IOS. In the study by Chochlidakis et al. (Chochlidakis et al., 2020), the True Definition IOS was used, and the deviations were also very high. A study by Schmidt, Schlenz, et al. (2021) confirmed that no better result was achieved with the True Definition IOS with its newer hardware generation in combination with newer software version. As the True Definition Scanner works on the active wavefront sampling recording principle with structured light projection and relies on the use of powder (Logozzo et al., 2014), the lower use of powder recommended by the manufacturer could hypothetically be responsible for the lower accuracy. In addition, the principle of the optical triangulation technique alone or in combination with confocal laser scanning microscopy is still available (Schlenz et al., 2020; Tewes & Berner, 2019). The remaining studies (Gedrimiene et al., 2019; Jiang et al., 2019; Rutkunas et al., 2020; Schmidt, Rein, et al., 2021) involved an average transfer deviation within 150 μm as required by Jemt (Jemt, 1991), but not within the 10 μm transfer deviation postulated by Brånemark (Brånemark, 1983).

In a few studies, the scanpath used has not been described. It is known that different scanpaths can lead to inaccuracies during transfer owing to possible matching or stitching errors during data acquisition. Therefore, the extent to which the scanpath can have a negative influence on the clinical impression in some of the studies in the present review remains unclear. Therefore, it is recommended to use the respective scanpath recommended by the manufacturer for data acquisition (Ender & Mehl, 2013; Müller et al., 2016).

Another influence can be attributed to the scanbody used. Regardless of the manufacturer, a structure that can be clearly detected by the IOS should be used. Furthermore, only scanbodies stored in the software library of the scanner or corresponding CAD software should be used (Schmidt et al., 2019; Schmidt et al., 2021b). For everyday clinical use, it should also be noted that the data from a received IOS are not used directly, but are first processed into a digital model using model builder software. This could potentially reduce acquisition errors during the process of matching the CAD data of the scanbody (from the model builder's software library) with the standard tessellation language (STL) dataset of the scanner. In clinical practice, the resulting error can be lower (Mizumoto et al., 2020). Particularly in the case of the study by Rhee et al. (Rhee et al., 2015), superimpositions were performed, but no numerical distance values were further defined. No numerical data for the superimpositions between conventional and digital impressions have been reported. Therefore, this study was excluded from Figure 2.

In addition to data acquisition, data evaluation can also have a decisive influence on accuracy. Moreover, some studies (K. Chochlidakis et al., 2020; Jiang et al., 2019) compared only the variations in superimpositions. While the use of a best-fit method typically produces numerically lower values, the values of a three-dimensional measurement were significantly higher. This method tends to hide real differences (Ameza-Lasuen et al., 2020; Schmidt et al., 2021, 2021a). However, this becomes apparent only when an external reference structure is used and is seen as a benchmark, without which the actual deviations in the transfer of the intraoral to the extraoral situation cannot be estimated. This is because the transfer of the intraoral structures, whether conventional or digital, always involves errors, but the extent of this error remains unknown in the absence of a reference. For this reason, an external reference structure is also regarded as a necessary prerequisite in the field of full-arch impressions to decide the more accurate impression method (conventional or digital) in each case (Keul & Güth, 2020; Kuhr et al., 2016; Schmidt, Klussmann, et al., 2020). In contrast to the best-fit method, the three-dimensional evaluation method allows accurate interpretation of the results, but this requires the presence of a reference structure. However, it should be noted in the overall concept of prosthetic treatment that although the intraoral impression is an essential aspect in the entire treatment chain, there are also other influences on the result, especially in the subsequent fabrication of the restoration.

The conventional impressions predominantly involved open impressions. Several previous studies have reported that these impressions revealed the highest accuracy, especially impressions of multiple implants (Flügge et al., 2018; Moreira et al., 2015; Stimmelmayr et al., 2012). Depending on the evaluation and analysis method used, deviations in the range of 45 μm (Schmidt, Rein, et al., 2021) to 160 μm (Alsharbaty et al., 2019) could be achieved by using analogue impression methods.

In summary, further clinical studies are desirable, wherein a reference construct is applied and the evaluation is performed using the same measurement methods. This is the only way the results of future studies can be better classified. For a uniform presentation of the results, ISO 5725-1 (International Organization for Standardization, 1994) was demonstrated to be effective, and the results are presented with trueness and precision.

5 | CONCLUSION

There are only a few clinical studies on the accuracy of digital implant impressions. Thus, the impact of different factors, such as the scanpath or scanbody, could not be identified. However, it could be shown that to date, the accuracy of recent IOS for digital implant impressions in patients is in a clinically acceptable range as previously suggested. Nevertheless, the transfer error still needs to be considered when manufacturing implant-supported restorations. Furthermore, future clinical studies regarding the accuracy of intraoral scans are desirable; for better comparability, the results should be presented in terms of trueness and precision.

AUTHOR CONTRIBUTIONS

Alexander Schmidt: Conceptualization (equal); Visualization (equal); Writing – original draft (equal). **Bernd Woestmann:** Supervision (equal); Writing – review & editing (equal). **Maximiliane Amelie Schlenz:** Conceptualization (equal); Visualization (equal); Writing – original draft (equal).

CONFLICT OF INTEREST

The authors declare that there are no conflict of interests related to this study.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

ETHICAL APPROVAL

Ethics approval was not required for this systematic review.

REGISTRATION

The review was not registered.

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