

# EPA Consensus Project Paper: Accuracy of Conventional and Digital Workflows in Partially Edentulous Cases Restored with FPDs over Implants. A Systematic Review

## Keywords

Accuracy  
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## ABSTRACT

*Purpose:* To compare conventional and digital workflows in terms of accuracy in partially edentulous cases restored with implant-supported restorations. *Methods:* An electronic search in the databases PubMed, Scopus, Web Of Science, and CENTRAL was conducted to identify relevant publications, comparing digital and conventional workflows in partially edentulous cases restored with implant-supported prostheses. *Results:* 18 articles were included in the systematic review. Ten of the studies were in-vitro, and eight were clinical. Sample sizes varied considerably from 20 to 100. In three studies, three implants were investigated, whereas, in all other instances, accuracy was evaluated on two implants. Substantial heterogeneity in the methodology of the selected studies is evident, which prevents summarising the accuracy outcomes. *Conclusions:* Digital impressions showed similar results in terms of accuracy compared to the conventional approach. There is a lack of uniform criteria for the tolerable misfit, which hampers the ability to transfer in-vitro results to clinical situations. A need for a standardised approach in the evaluation of impression and workflow accuracy is warranted to enable the systematisation and analysis of results from different studies.

## INTRODUCTION

Digital dentistry is rapidly changing the way prosthodontic work is organized and executed. Sufficient published data supports the most quoted benefits, such as clinical and laboratory optimization, more predictable overall results, and increased quality of restorations due to the reduction of human error.<sup>1,2</sup> More importantly, there is a general paradigm shift in planning and execution in complex prosthetic cases with a promise of increased accuracy and predictability of outcomes.<sup>3,4</sup> The latter is especially true for complex restorations supported by implants, where a frequent scenario is a fixed partial denture.<sup>5</sup>

Several techniques are routinely implemented to assess the accuracy of impression methods and finished restorations. The most commonly used ones rely on direct marginal gap evaluation via observation, probing or x-ray evaluation.

A quantitative approach to determining impression quality is the evaluation of accuracy, and the latter is defined in ISO5725-1 as a combination between trueness and precision. Trueness is the measurement bias between a reference object and a target object, whereas precision is the random error in reproducibility between objects when the process is repeated.<sup>6,7</sup>

Even minor mistakes in information acquisition (e.g., impression-taking, conventional or digital) and fabrication can lead to catastrophic failures and the need to remake the manufactured constructions. A crucial element in successful implant-facilitated oral rehabilitation is the passive fit of the fabricated framework. Shortcomings in this regard can lead to various technical and biological complications ranging from prosthetic screw loosening or fracture to microorganism accumulation.<sup>8,9</sup>

Several reviews combine the available information on the accuracy and precision of different acquisition techniques and digital workflow fabrication methods.<sup>1,4,8,10,11</sup> However, clinical outcomes do not solely depend on a single stage in the process but are the sum of successful planning and execution across all phases of treatment.

Thus, we aim to investigate the entire treatment process, combining and systematically analyzing the available data. Furthermore, a comparison of the reported outcomes from conventional and digitally assisted procedures will be developed, summarising the significant findings, including topics needing further research.

## MATERIALS AND METHOD

This systematic review was conducted following the guidelines of Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA Statement).<sup>12</sup> This review was registered to Prospero with ID number: CRD42021288513.

### FOCUSED QUESTION

Is “digital workflow” comparable to “classical/conventional workflow” regarding impression and finished restoration accuracy in partially edentulous cases restored with implant-supported FPDs?

### SEARCH STRATEGY

#### Database Selection

Search APIs connected to different databases considered in this systematic review were PubMed, Scopus, Web Of Science, and CENTRAL.

#### Definition of PICOS

We used PICOS: (Patients, Intervention, Comparison, Outcome, Study Design) to define the inclusion and exclusion criteria for the study (See Table 1).

**Table 1. The defined PICOS for the current systematic review.**

<b>Patients:</b>	Partially edentulous dental arches, or in cases of <i>in-vitro</i> studies, replicas of the latter.
<b>Intervention:</b>	Optical/digital impression and CAD/CAM fabrication of fixed implant-supported FPDs
<b>Comparison:</b>	Classical/conventional versus digital workflows
<b>Outcomes:</b>	Quantitative measurement of accuracy or precision (linear, angular, 3Dimensional – Hausdorff distance; Heatmaps).
<b>Study design:</b>	<i>in-vivo</i> and <i>in-vitro</i> experimental studies, controlled trials.

For this systematic review, case reports, letters to the editor, and studies that did not match the objectives defined by the PICOS were excluded. Furthermore, articles investigating single implants or completely edentulous patient scenarios were not considered.

### Keywords Selection and Search Query Definition

A preliminary (naive) search was done in PubMed. The search terms are based on the defined PICOS and were selected during a brainstorming session between the authors. The exact combination used was as follows: “(edentulous AND (partial\*)) AND ((dental implants) OR (dental implant)) AND (((Fixed partial dentures) OR (FPD) OR (FPDs)) OR (((impression) OR (dental impression) OR (dental impression technique) OR (scan) OR (dental scan) OR (intraoral scan) OR (intraoral scan) OR (intra-oral scan) OR (laboratory scan) OR (desktop scan)) OR ((conventional) OR (classical) OR (physical) OR (optical) OR (digital)))) AND ((accuracy OR precision OR trueness) OR ((measurement OR fit) AND (dimensional OR Linear OR Angular OR marginal OR internal)))”.

The results from the naïve search were exported and loaded in R within the package “litsearchR” to identify potential keywords, build the final search strategy and check its comprehensiveness.<sup>13</sup> A thorough keyword selection process was carried out. The keywords in the retrieved articles were combined, and automatically derived terms from the Titles and Abstracts were added. For this purpose, Rapid Automatic Keyword Extraction (RAKE) was used.<sup>14,15</sup> The extracted terms were evaluated for relevancy and assigned to one of the (PICOS) categories. The search query was built automatically using the “write\_search” function in litsearchr, and is presented below:

((“dental implant” OR implant OR mandible OR “partially edentulous” OR “fixed partial” OR “partial dentures” OR “definitive casts”) AND (“digital impression” OR “intraoral scanner” OR “implant impression”) AND (cad OR cam OR computer-assisted OR “digital workflow” OR “intraoral scanner” OR “conventional implant” OR “digital implant” OR “impression technique” OR traditional))

The search was conducted using an „English“ language filter covering the period 01.01.2011 – 31.12.2021. The last search was done on the fourth of January, 2022.

The comprehensiveness of the employed search strategy was evaluated through comparison with gold-standard articles identified throughout the naïve search and yielded a perfect match.<sup>16-19</sup>

### Retrieved Records and Exclusion Process

The resulting records from each database are presented in Table 2.

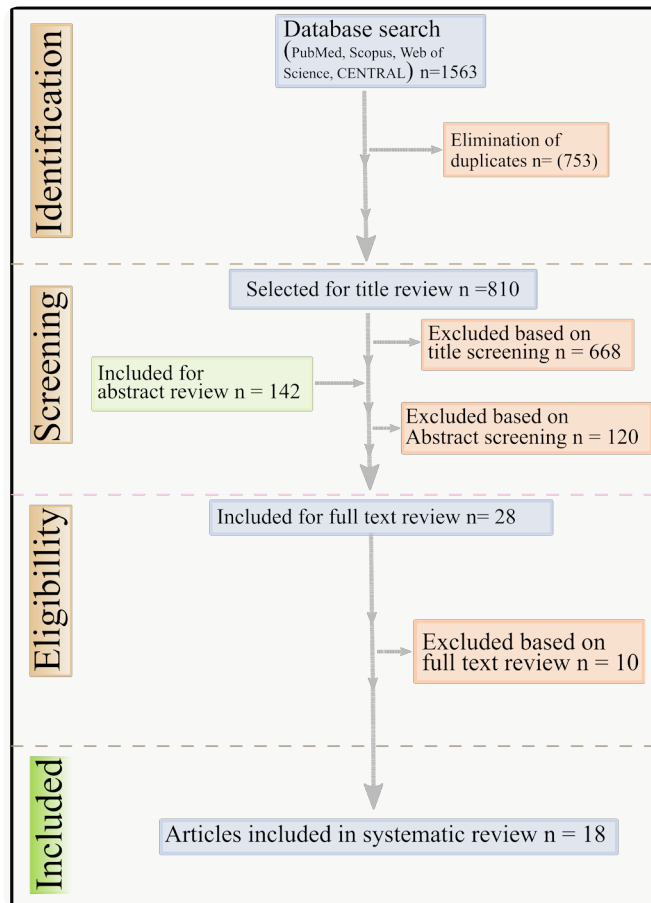
**Table 2. Records retrieved from each database employing the selected search strategy.**

Database	Records returned
PubMed	454
Scopus	584
Web of Science	433
CENTRAL	65
<b>Total</b>	<b>1.563</b>

After duplicate removal, the final count of records was 830. Following the defined inclusion and exclusion criteria, the records were screened in a multi-stage process depicted in Figure 1. Two authors (S.Z. and V.I.) evaluated the articles independently, and any disagreements were resolved by the third author (E.M.) and through discussion. Furthermore, references from all articles as of the final selection and existing systematic reviews on the topic were screened manually for any potential records not identified with the current search strategy. The Kappa coefficient was used to check consistency in the article selection process at the inter-reviewer level. The corresponding scores were 0.76, 0.82, and 0.95 for the title, abstract, and full-text exclusion levels, considered adequate levels for agreement.<sup>20</sup>

### Data Extraction and Method Of Analysis

The data of all included studies were extracted independently using data extraction tables developed by the authors. The considered data are summarised in Table 3. The information was compared between the reviewers and double-checked. Any issues during the data extraction were discussed within the group until an agreement was reached. Statistical analysis (e.g., Meta-analysis) was considered inappropriate in this review due to the lack of standardization and heterogeneity in the study design, the method and type of accuracy evaluation, the clinical scenario or laboratory replica under investigation, and devices and materials used in the included studies.



**Figure 1: PRISMA flow diagram: studies selection process.**

## RESULTS

The number of retrieved records and the study selection process is presented in Table 2 and Figure 1. The final number of articles included for analysis is 18. From the included records, 10 are *in-vitro*.<sup>16-19,21-26</sup> Eight articles compared accuracy outcomes for digital and conventional workflows in a clinical setting.<sup>9,27-33</sup>

The information extracted from the articles is summarised in Table 3 and includes data relevant to the study design and accuracy measurements. The sample size varied considerably - from 20 to 100. In most studies, accuracy in two implant scenarios was evaluated, whereas, in two clinical and one *in-vitro* investigation, accuracy outcomes in three implants scenario were analyzed.<sup>18,32,33</sup> In nine of the included articles, implant angulation was not considered, and it varied considerably in the remaining included titles (Table 3).<sup>9,17,18,24,27-29,33</sup> While the angle between implants was set at 30° in the studies by Marghalini *et al.* and Alshawaf *et al.*, Schmidt *et al.* considered a value below 15° for angular implant deviation.<sup>22,23,32</sup> The remaining titles evaluated impression accuracy based on different inter-implant angles.<sup>16,19,21,25</sup>

All impressions in the included studies were taken at the implant level. The impression technique for the conventional group was predominantly open-tray, with six articles using the non-splinted method and 12 using transfer splinting with various

Table 3. Data extracted from the selected studies.

Author & Year	Study type	Sample size	Number of Implants	Angulation	Impression techniques	Method for accuracy assessment	Conventional impression material	Scanner brand	Implant/scan body brand	Comparison outcomes
Lin et al. 2015 <sup>16</sup>	<i>in-vitro</i>	80	2	0, 15, 30, 45	Implant level, non-splinted, Open tray	Angular and Linear discrepancy (virtual models superimposition)	PVS	iTero (Cadent)	Straumann TL	CI>DI, DI improves at a higher angulation
Basaki et al. 2017 <sup>21</sup>	<i>in-vitro</i>	40	2	0, 10, 30	Implant level, non-splinted, Open tray	Angular and Linear discrepancy (virtual models superimposition)	PVS	iTero (Cadent)	Straumann BL	CI>DI
Chew et al. 2017 <sup>17</sup>	<i>in-vitro</i>	40	2	NA	Implant level, non-splinted, Open tray	Angular and Linear discrepancy (CMM)	Polyether	Trios (3Shape), iTero (Cadent), True Definition	Straumann BL, Straumann TL	CI>DI for BL, CI=DI for TL
Chia et al. 2017 <sup>19</sup>	<i>in-vitro</i>	60	2	0, 10, 20	Implant level, non-splinted, Open tray	Angular and Linear discrepancy (CMM)	Polyether	Trios (3Shape)	Straumann BL	CI>DI in parallel implants, CI=DI for angulated
Marghalini et al. 2017 <sup>23</sup>	<i>in-vitro</i>	30	2	30	Implant level, splinted, Open tray	3D deviation (virtual model superimposition)	Polyether	True Definition, Cerec Omnicam	Straumann TL, Nobel replace	DI>CI; TD>CO
Alshawaf et al. 2018 <sup>22</sup>	<i>in-vitro</i>	30	2	30	Implant level, splinted, Open tray	3D deviation (virtual model superimposition)	Polyether	True Definition, Cerec Omnicam	Nobel Replace	CI>DI; CO>TD
Alsharbaty et al. 2019 <sup>27</sup>	clinical	36	2	NA	Implant level, splinted, Open tray, Closed tray	Angular and Linear discrepancy (CMM+virtual model superimposition)	PVS	Trios3 (3Shape)	Implantium (internal connection)	CI>DI
Jiang et al. 2019 <sup>28</sup>	clinical	34	2	NA	Implant level, splinted, Open tray	3D deviation (virtual model superimposition)	Not disclosed	Trios3 (3Shape)	Camlog Screw-Line Implant, Camlog Scanbodies, Camlog Biotechnologies AG, Basel, Switzerland	CI=DI
Bohner et al. 2019 <sup>18</sup>	<i>in-vitro</i>	20	3	NA	Implant level, splinted, Open tray	3D deviation (virtual model superimposition)	PVS	Dental Wings (Straumann)	S.I.N implants	CI>DI
Gedrimiene et al. 2019 <sup>29</sup>	clinical	48	2	NA	Implant level, splinted, Open tray	Center point, angular deviation, rotation, vertical shift, surface mismatch (virtual model superimposition)	PVS	Trios3 (3Shape)	AnyOne (MegaGen, Daegu, South Korea)	CI ≠ DI with potential clinical significance

Table 3 continued overleaf

**Table 3.** Data extracted from the selected studies continued...

<b>Rutkunas et al. 2020<sup>9</sup></b>	clinical	48	2	NA	Implant level, splinted, Open tray	Distance, angulation and surface mismatch (virtual model superimposition)	PVS	Trios3 (3Shape)	AnyOne (MegaGen, Daegu, South Korea)	CI≠DI with potential clinical significance
<b>Rutkunas et al. 2020<sup>30</sup></b>	clinical	48	2	NA	Implant level, splinted, Open tray	Screw resistance test	PVS	Trios3 (3Shape)	AnyOne (MegaGen, Daegu, South Korea)	DI>CI
<b>Roig et al. 2020<sup>24</sup></b>	in-vitro	70	2	NA	Implant level, splinted, non-splinted, Open tray, Closed tray	3D deviation - centroid point, Angular and Linear discrepancy (virtual model superimposition)	Polyether	Trios3 (3Shape), CS3600 (Carestream), CEREC Omnicam (Dentsply Sirona)	C1 MIS, Scan Post CS-SP102	DI>CI
<b>Rutkunas et al. 2021<sup>31</sup></b>	clinical	48	2	NA	Implant level, splinted, Open tray	Prosthesis fit and cement gap (SEM) analysis	PVS	Trios3 (3Shape)	AnyOne (MegaGen, Daegu, South Korea)	Dmisfit - CI>DI; Dcement DI>CI
<b>Abduo et al. 2021<sup>25</sup></b>	in-vitro	100	2	0, 15	Implant level, splinted, Open tray, Closed tray	Angular and Linear discrepancy (virtual models superimposition)	PVS	Trios 4 (3Shape), Medit500, True Definition	Straumann TL	DI>CI
<b>Mathey et al. 2021<sup>26</sup></b>	in-vitro	20	2	NA	Implant level, non-splinted, open tray	Angular and Linear discrepancy, surface deviation (virtual models superimposition)	Polyether	Trios 3 (3Shape)	Straumann TL	CI=DI
<b>Schmidt et al. 2021<sup>32</sup></b>	clinical	39	3	<15	Implant level, splinted, Open tray, reference key*	center point deviation (CMM, virtual metrology software)	Polyether	Trios 3 (3Shape)	ProActive Straight (Neoss, Cologne, Germany); Straumann BL	CI=DI
<b>Nagata et al. 2021<sup>33</sup></b>	clinical	30	2,3	NA	Implant level	3D deviation (virtual model superimposition)	PVS	Trios 3 (3Shape)	Straumann BL/Mono Scanbody RC	sig. difference, deviation <100 µm

NA – not applicable; CMM – coordinate measuring machine; 3D – Three dimensional; SEM – scanning electron microscope; PVS – polyvinyl siloxane; CI – conventional impression; DI – digital impression

techniques and materials. Roig *et al.* used both splinted and non-splinted methods for conventional impressions.<sup>24</sup> In one of the articles, no information for the exact impression technique was identified.<sup>33</sup> Several studies directly compared splinted vs non-splinted techniques or open vs closed trays.<sup>24,25,27</sup> In one article, a custom impression jig was used.<sup>32</sup> The impression materials used in the conventional group were 10 for PVS and 7 for Polyether. In one study, the impression material was not disclosed.<sup>28</sup>

In terms of brand, device and software generation, different intraoral and extraoral digitalization systems were employed (Table 3). In five articles, more than one system for digitization was employed, facilitating a digital-digital comparison besides the digital-conventional.<sup>13,18-21</sup> The most frequently used intraoral

scanners in two-thirds (66.6%) of the included studies were Trios3 (3Shape, Copenhagen, Denmark).<sup>7,15,17,20,22-29</sup>

One article evaluated the marginal fit and cement gap size for the produced FPDs using SEM analysis. The reported values for marginal fit (digital – 77±88 µm; 59±60 µm) and cement gap (digital – 35±26 µm; conventional 38.9±23 µm) differed significantly between the groups.<sup>27</sup> In another study, Rutkunas *et al.* evaluated screw resistance as a measure of accuracy, reporting different values based on the reference model – intraoral (digital - 13.85 ± 10.78°; conventional - 16.25 ± 15.52°), master cast (digital - 13.12 ± 13.86°; conventional - 6.04 ± 7.43°).<sup>26</sup>

Methods for direct accuracy comparison between digital and conventional impressions varied considerably, including Angular and Linear discrepancy, centre point deviation, inter-implant distance, and surface mismatch.

Four articles assessed accuracy-related parameters through a Coordinate Measuring Machine (CMM).<sup>17,19,27,32</sup> In their article, Chew *et al.* used a CMM for the physical models and a virtual CMM for the studied .stl files. The reported mean accuracy outcomes ranged from 35 to 66  $\mu\text{m}$  for the global linear distortion,  $0.5^\circ$  and  $0.37^\circ$  for the mean y and x angular deviations, respectively.<sup>17</sup> In another study by Chia *et al.*, a similar methodology was employed. The reported mean values ranged from 18 to 45  $\mu\text{m}$  for the global linear distortion,  $0.04^\circ$  to  $0.79^\circ$  and  $0.07^\circ$  to  $0.19^\circ$  for the x and y absolute angular deviations.<sup>19</sup> In a clinical study, Alsharbaty *et al.* used a CMM for the physical models produced from conventional impressions and a 3D evaluation software for the measurements of digital impressions. The authors evaluated angular, linear displacement and deviation in the distance between the implants. Their results showed unacceptable performance of the digital impression methods with values exceeding a clinically acceptable threshold –  $6.77^\circ$  for angular displacement, 360  $\mu\text{m}$  for linear displacement, and 220  $\mu\text{m}$  for displacement in the position.<sup>27</sup> In another clinical study by Schmidh *et al.*, a specific key-reference jig was used to determine the difference in accuracy in a three-implant scenario. The authors used a CMM and metrology software to compare the deviation in the centre points of implants as a measure of accuracy. The reported outcomes for partially edentulous patients were  $53\pm 31$   $\mu\text{m}$  for the conventional impression technique and  $43\pm 31$   $\mu\text{m}$  for the optical impression, with no statistically significant difference between both groups.<sup>32</sup>

The remaining studies employed a virtual superimposition methodology.<sup>9,16,18,21-26,28,29,33</sup> In their study, Lin *et al.* reported accuracy values based on distance and angular deviation. The results suggest that using digital impressions to produce definitive working models is significantly less accurate than their conventional counterparts for both studied variables. Furthermore, a negative accuracy trend was observed for the digital group regarding a lack or low ( $0^\circ$ ,  $15^\circ$ ) implant divergence.<sup>16</sup> In their study, Basaki *et al.* evaluated the difference between digital and conventional impressions using a 3D error parameter based on centre point deviation, inter-implant angulation and verification jig assessment. The authors reported a clinically unacceptable deviation range (21-298  $\mu\text{m}$ ) in the digital impression group and an acceptable fit of the verification stent in only 55% of the resulting models. No difference between the two studied groups was found for the inter-implant angulation parameter.<sup>21</sup> Marghaliani *et al.* investigated the accuracy between a conventional impression technique and two optical scanners with two implant systems using the root mean square method for calculating the error. The reported outcomes showed significantly better performance for the digital impression groups with the highest difference value of

33  $\mu\text{m}$ . Nevertheless, the recorded error for the conventional group (range 24-53  $\mu\text{m}$ ) falls within the clinically acceptable limit.<sup>23</sup> A similar study by Alshawaf *et al.* reported a maximum error in the digital group of 131.25  $\mu\text{m}$ . The lowest recorded value was in the conventional group – 39.41  $\mu\text{m}$ .<sup>22</sup> In their clinical study, Jiang *et al.* reported a difference between the conventional splinted open tray technique and the digital impression of  $27.43\pm 13.57$   $\mu\text{m}$ , ranging from 12.19 to 54.87  $\mu\text{m}$ .<sup>28</sup> Bohner *et al.* proposed an alternative digital/conventional impression accuracy evaluation method. The authors analyzed cast fabricated by conventional or digital means by assessing 3D deviation and distances between points of interest. The values obtained for the former did not reveal a statistically significant difference (conventional –  $16.20 \pm 14.50$   $\mu\text{m}$ , digital –  $19.70 \pm 13.30$   $\mu\text{m}$ ). However, two of the three measured distances showed markedly lower performance in the digital group.<sup>18</sup> Gedrimiene *et al.* and Rutkunas *et al.* performed a clinical study using similar methods and populations. In both studies, several parameters were used to determine the accuracy outcome – inter-implant distance:  $72.25\pm 67$   $\mu\text{m}$ ; Angulation:  $0.41\pm 0.3^\circ$ ; Rotation:  $1.36\pm 0.96^\circ$ ;  $90.55\pm 79$   $\mu\text{m}$ . Both articles found significant differences between digital and conventional impressions, with errors in several cases exceeding the assumed clinical significance threshold of 100  $\mu\text{m}$ .<sup>9,29</sup> In their *in-vitro* study, Roig *et al.* investigated the difference in accuracy between four IOS systems and three conventional impression techniques using inter-implant centroid distance, rotation, and precision. The authors reported similar mean centroid distances between the digital and conventional groups (ranging from 12  $\mu\text{m}$  to 235  $\mu\text{m}$ ). All analyzed impression systems showed a certain degree of rotation ranging from  $86^\circ$  to  $92^\circ$ . Regarding the precision parameter, the digital group performed more than four times better (mean 33  $\mu\text{m}$ ) than the conventional (mean 154  $\mu\text{m}$ ).<sup>24</sup> Abduo *et al.* compared three optical impression devices and splinted and non-splinted open-tray conventional impressions in parallel and non-parallel two-implant scenarios. The authors concluded that digital impressions perform equal or superior to conventional in terms of accuracy.<sup>25</sup> In their *in-vitro* study, Mathey *et al.* compared digital and conventional impressions of two implants by evaluating the trueness, precision and 3D vector deviation of the resulting master casts. The authors reported a statistically significant difference only for the trueness parameter between the optical ( $106\pm 104.40$   $\mu\text{m}$ ) and analogue ( $187.90\pm 181.20$   $\mu\text{m}$ ) groups. For the 3D deviation analysis, it was noted that the Z-axis (vertical) deviations were the highest (conventional –  $2.26\pm 71.40$   $\mu\text{m}$ ; digital –  $50.16\pm 79.67$   $\mu\text{m}$ ).<sup>26</sup> In a clinical study, Nagata *et al.* evaluated the misfit of scan bodies screwed to models acquired from optical and conventional impression techniques. They found a clinically acceptable error, with the highest reported deviation of  $80.3\pm 12.4$   $\mu\text{m}$  between both groups.<sup>33</sup>

## DISCUSSION

The included articles in this systematic review evaluated the trueness and precision of digital compared to conventional impressions for implant-facilitated rehabilitation of partially edentulous dental arches. Only direct comparison studies with either digital or conventional control groups were selected to eliminate differences in operator experience (where applicable), experimental conditions, and specific study design. However, a lack of homogeneity between the included studies was evident when reviewed. There are differences in study design regarding impression accuracy analysis and comparison between groups, methods, devices, and impression-taking materials. A study by Schmidt *et al.* demonstrates that various methods for analyzing digital data can lead to significantly different results.<sup>34</sup> When attempting to combine and statistically analyze results from multiple studies, the latter must be considered. Furthermore, the investigated clinical or *in-vitro* experimental settings significantly differ in terms of the number of implants, inter-implant distance, area, and angulation, which might further cause heterogeneity in the results.

Eight studies included in this review compared the accuracy of data acquisition between digital and conventional methods in a clinical setting.<sup>9,27-33</sup> Including clinical studies in this review has advantages and disadvantages. The main benefit of clinical investigations is the easier translation of the obtained results to a daily treatment scenario, including factors influencing the outcomes, such as operator, saliva, anatomic conditions, lighting, and behaviour of impression materials in the oral cavity.<sup>26</sup> The positions of the implants in the mouth cannot be obtained using a high-precision reference instrument such as CMM or industrial-grade optical scanner, which obstructs the fabrication of a reference model and the following determination of trueness for both conventional and digital data acquisition protocols.<sup>35</sup> Nevertheless, a comparison between methods, especially in the domain of precision, is feasible.

The reported outcomes from the clinical studies are highly heterogeneous. Most authors conclude that the digital pathway produces impressions of sufficient quality for fixed implant-supported prostheses in partially edentulous cases. It must be noted that half of the included clinical studies investigate the same or similar populations.<sup>9,29-31</sup> The authors suggest different means to evaluate the accuracy parameter from clinical experiments. Hence, it was deemed useful to include them in this review. Furthermore, in one of the studies, only descriptive statistics for both digital and conventional groups are presented without directly comparing them.<sup>28</sup> Attempting to summarize the outcomes is impractical because of the quoted reasons and the heterogeneity in methods and materials used.

Ten of the included studies investigated the accuracy of optical and conventional impression techniques in an *in-vitro* setting.<sup>16-19,21-26</sup> One included study investigated a three-implant scenario, whereas all others evaluated the impression accuracy

of two implants (*Table 2*). Seven out of the ten articles concluded that conventional impressions are significantly more accurate than their digital counterparts.<sup>16-19,21,22</sup> Furthermore, Chew *et al.*, and Chia *et al.* reported no differences between the investigated groups in specific conditions – tissue-level and angulated implants, respectively.<sup>17,19</sup> Moreover, in a more recent study, Mathey *et al.* found no difference in accuracy between digital and conventional impressions.<sup>26</sup> Only three studies concluded that digital systems perform better than analogue ones.<sup>23-25</sup> It must be noted that more recent studies employing newer generations of software and hardware report better outcomes for optical impressions. A numerical summary or direct comparison between most of the included studies is not feasible due to the vast differences in research design, methods and accuracy evaluation technique. However, in the studies of Marghaliani *et al.* and Alshawaf *et al.*, a similar reference model and accuracy determination procedures were used.<sup>22,23</sup> Despite that, the reported results are contradictory, which might be attributed to the different implants used in one of the quoted studies (Strauman TL) and other factors influencing the quality of optical scans, such as operator experience, scanning strategy, ambient lighting, temperature and humidity.<sup>36</sup>

A variable of clinical importance – the influence of implant angulation on the accuracy outcome, was investigated in four studies.<sup>16,21,19,25</sup> Basaki *et al.* reported that implant divergence had no significant influence on overall accuracy.<sup>21</sup> Authors in the remaining studies concluded that implant angulation significantly affected impression accuracy.<sup>16,19,25</sup> All three studies report that increasing inter-implant divergence results in less favourable conditions for taking conventional impressions while minimally affecting the accuracy of digital impressions.

Our initial aim was to compare the accuracy of digital and conventional procedures in the implant-supported prosthetic rehabilitation of partially edentulous patients. The main determinants for accuracy include the steps of data acquisition and prosthesis fabrication. The first phase is thoroughly researched in several studies systematized in this review and previously published work.<sup>2,37-39</sup> Several articles were identified using the current search strategy, comparing digital and conventional fabrication techniques for FPDs supported by natural teeth, and only a few studies evaluated the precision and marginal discrepancies for FPDs over implants in partially edentulous cases.<sup>9,31,40-45</sup> However, a direct comparison between conventional and digital manufacturing methods for FPDs restoring partially edentulous spaces is lacking in the literature. As with prepared teeth, the morphology of implant abutments varies considerably between systems. Implant abutment libraries, software tools for digital design, and the type of digitally facilitated manufacturing – milling or 3D printing might also influence the outcome. It may be prudent to conduct experimental studies considering the abovementioned factors to estimate the optimal workflow for this phase of the prosthetic treatment.<sup>10,46</sup>

## CONCLUSION

There is limited information in the literature with sufficient quality to support either protocol (digital or conventional) in PE cases employing implant-supported restorations. Nevertheless, some preliminary conclusions can be drawn. In PE patients IOS might provide sufficient quality and be considered suitable for routine clinical use. Moreover, digital impressions seem to outperform their conventional counterparts in cases with tilted implants, despite having a lower overall accuracy. A trend of increased accuracy with the newer software and IOS devices must be noted. The results from this systematic review cannot be used to formulate a practical clinical guideline since most studies are *in-vitro*, lacking some critical conditions present in actual clinical scenarios, among other shortcomings. The development of study designs and experimental protocols is needed to ensure high-quality evidence and a reliable method for determining the accuracy of all steps included in fixed prosthetic rehabilitation over implants in a clinical setting.

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