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Original Article

Dentistry Section

Accuracy, Efficacy and Reliability of Extraoral Scanners: A Systematic Review

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ABSTRACT

Introduction: Extraoral Scanners (EOS) have become fundamental tools in digital workflows, enabling precise digitisation of dental impressions, casts, and prosthetic components. Despite the technological advancements, the success of any digital workflow is highly dependent on the quality of the input data provided by the scanning system. This highlights the critical importance of evaluating the accuracy, efficacy, and reliability of EOS.

Aim: The purpose of the present systematic review is to evaluate the accuracy, efficacy and reliability of EOS.

Materials and Methods: An electronic search (PubMed, Scopus, Cochrane Library, Web of Science, Google Scholar) was used to find the pertinent publications written exclusively in English and published up until November 2024. Based on the Population, Intervention, Control, and Outcomes (PICO) framework, the main research question for the present study was "How is the accuracy, efficacy and reliability of EOS?" By looking at the titles, abstracts, and full texts of the articles, it was possible to verify their relevance and see if they met the inclusion criteria. Quality assessment was conducted using the QUIN tool for in-vitro studies and the JBI tool for analytical cross-sectional studies.

Results: Out of the 139 results returned by the database search, 118 were removed due to incomplete, inconsistent, or missing information. Three papers were removed after 21 full-text papers were evaluated for eligibility. Accordingly, a total of 14 studies were included in the present systematic review. Meta-analysis was not performed due to significant heterogeneity among the included studies.

Conclusion: Most of the available studies indicate that EOS demonstrate higher accuracy when compared to intraoral scanners. This accuracy is generally evaluated in terms of trueness and precision, which are crucial parameters for ensuring the success of various prosthetic restorations. EOS, by minimising distortions and providing more consistent digital impressions, hold promising results for improving the overall quality of prosthesis fabrication.

Keywords: Accuracy of scanners, Digital impression technique, Extraoral impressions, Extraoral scanners

INTRODUCTION

Intraoral replication of dental arches has traditionally relied on conventional elastic impression materials such as alginate, polyvinyl siloxane, and polyether, which reproduce intraoral anatomy through material deformation followed by gypsum cast fabrication [1]. These conventional techniques are prone to limitations including dimensional instability, polymerisation shrinkage, stone expansion, technique sensitivity, patient discomfort, and cumulative inaccuracies arising during impression disinfection, transportation, and cast pouring [2]. Digital technology has transformed the diagnostic and restorative workflow in modern dentistry, with extraoral laboratory scanners becoming one of the most indispensable tools in the fabrication of precise dental restorations. The concept of digital intraoral scanning and Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) dentistry was first proposed by François Duret in 1973, who described the use of optical impressions for computerised dental restorations [3]. This concept was later translated into clinical practice by Mörmann and Brandestini with the development of the first commercially available chairside CAD/CAM system (CEREC) in the 1980s [4]. Precision in digital workflows is particularly critical for producing well-fitting fixed prostheses, implant frameworks, orthodontic appliances, and full-arch rehabilitations. Therefore, understanding how EOS perform in terms of trueness, precision, reproducibility, and clinical feasibility is fundamental for ensuring predictable treatment outcomes [5].

The CAD/CAM systems use standardised manufacturing procedures and industrially prepared materials to create restorations of higher quality. The workflow consists of three main steps-surface scanning, restoration designing and manufacturing. There are two primary kinds of dental CAD/CAM scanners: EOS are used in dental laboratories to scan casts, and intraoral scanners are used chairside to scan patients' dental arches. Both kinds of scanners use CAD software to create a digital model of the patient's mouth. At the end with the help of polymers, ceramics or other material the model is fabricated with CAD/CAM technology [6]. Three primary technologies are used by EOS: touch, structured light, and laser. The density of the object being scanned has no effect on optical scanners (both laser and structured light) since they don't need physical contact. In addition, they are frequently quicker than touch scanners. Nevertheless, the object being scanned has surface shine and brightness but other optical characteristics have no effect on these scanners [7].

Accuracy ensures that the digital model reflects the true anatomy without distortion. Efficacy measures the scanner's ability to deliver usable results efficiently and consistently. Reliability guarantees consistent performance over time, which is essential for clinical reproducibility and long-term success of restorations [8]. Accuracy, often subdivided into trueness and precision, is the most essential performance measure for any scanning system. Trueness refers to the closeness of a scan to the actual geometry of the object, while precision denotes the repeatability of scans taken under similar conditions. EOS, unlike intraoral systems, capture dental models or impressions outside the oral environment, thereby eliminating intraoral variables such as saliva, soft-tissue interference, patient movement, and limited intraoral access. This controlled environment provides a theoretical advantage in achieving higher scanning accuracy, especially for long-span or complete-arch applications.

Several studies have systematically compared intraoral and extraoral systems to validate these claims [8,9].

The existing literature on extraoral dental scanners has predominantly investigated their accuracy, trueness, precision, and reliability for digitising dental casts and implant models under controlled laboratory conditions. Early three-dimensional (3D) validation studies demonstrated that EOS provide clinically acceptable accuracy when compared with contact digitisation methods, particularly for single-tooth and short-span restorations [10]. Subsequent in-vitro studies comparing multiple EOS reported that scanning accuracy is strongly influenced by scanner technology, optical principles, resolution, and calibration protocols, with structured-light and blue-light scanners generally outperforming laser-based systems in terms of precision [6,9]. Several investigations have shown that EOS exhibit higher precision than intraoral scanners for complete-arch digitisation, largely due to stable scanning environments and the absence of intraoral factors such as saliva, limited access, and patient movement [7,11].

Despite the technological advancements, the success of any digital workflow is highly dependent on the quality of the input data provided by the scanning system. Although a growing number of studies support the clinical applicability of EOS, no universal consensus exists regarding their overall accuracy, efficacy, and reliability across different clinical indications, such as in fixed prosthodontics and implant dentistry [12,13]. Consequently, a systematic review is warranted to critically appraise and synthesise the available evidence using standardised criteria, evaluate the quality and risk of bias of existing studies, identify factors influencing scanner performance, and provide evidence-based guidance for clinical decision-making and future research regarding evaluating the accuracy, efficacy, and reliability of EOS. Thus, the systematic review was conducted with the research question: Do EOS provide clinically acceptable accuracy, efficacy, and reliability for use in CAD/CAM workflows?

MATERIALS AND METHODS

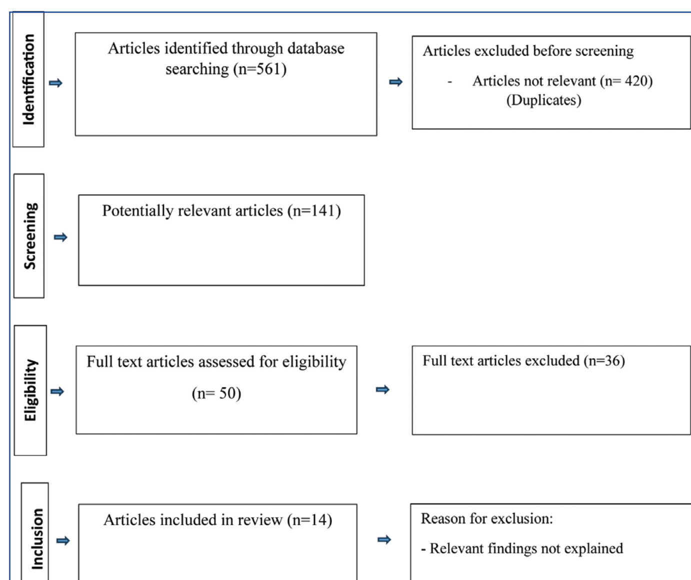
The present systematic review adhered to the preferred reporting items. The PRISMA flowchart for the review has been given in [Table/Fig-1].

PICO Question

All the studies investigating accuracy, efficacy and reliability of EOS Were:

P (Population/Problem): - Partially/Completely edentulous arches.

I (Intervention): Use of EOS (e.g., 3D facial scanners, cone-beam CT, structured light scanners).



[Table/Fig-1]: PRISMA flow chart.

C (Comparison): Conventional methods (e.g., manual measurements, two-dimensional (2D) imaging, intraoral scanning where relevant) or other digital scanning techniques.

O (Outcome): Accuracy, efficacy, and reliability in capturing anatomical data for clinical or diagnostic purposes.

Inclusion criteria: The research considered in the present systematic review comprised pilot studies, Randomised Controlled Trials (RCTs), cross-sectional studies, retrospective studies, prospective studies on EOS describing about the accuracy, efficacy and reliability in different prosthodontic restorations published between 1990 and 2024. Only English-language articles were considered.

Exclusion criteria: Systematic reviews were excluded. Narrative review, conference preceding, short communication was not included. Studies which are not in English language and which do not match the time period of the systematic review were excluded.

Study Procedure

Search strategy: An electronic search was carried out across several databases, to identify relevant articles published up to November 2024. The search was limited to articles written in English. To define the search strategy, a combination of controlled vocabulary (MeSH terms in PubMed) and free-text terms from titles and abstracts was used. The search strategies were constructed using keywords corresponding to each section of the PICO question, connected by the Boolean operator OR. Finally, all sections were combined using the Boolean operator AND. Additionally, relevant studies were identified by searching within the references of articles from these journals [Table/Fig-2].

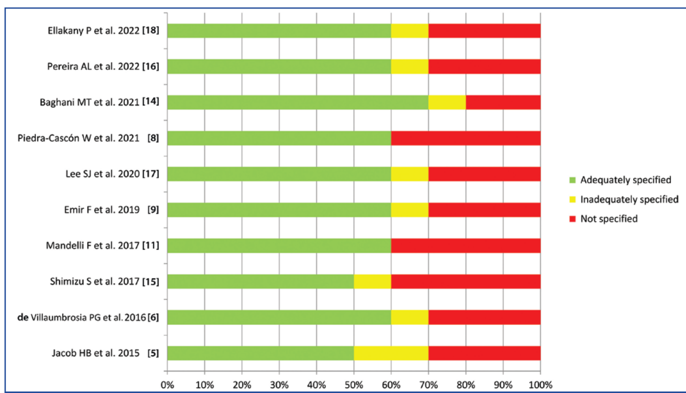
Database	Keyword Combination and Boolean Operators	No. of article hit
PubMed	extraoral scanner, accuracy, efficacy, reliability, 3D scanning, digital impression ("extraoral scanner" OR "extra-oral scanner") AND ("accuracy" OR "precision") AND ("efficacy" OR "performance") AND ("reliability" OR "repeatability")	139
Scopus	extraoral scanner, dental scanning, structured light scanning, 3D imaging ("extraoral scanner" AND "digital dentistry") OR ("structured light scanning" AND "accuracy")	110
Cochrane Library	extraoral scanner, digital impression, 3D scanning ("digital impression" OR "3D scanning") AND ("accuracy" OR "reliability")	95
Web of Science	extraoral scanner, measurement accuracy, dental CAD/CAM ("extraoral scanner" AND "measurement accuracy") OR ("dental scanning" AND "reliability")	97
Google Scholar	extraoral scanner, 3D imaging, performance, repeatability ("extraoral scanner" AND "3D imaging") AND ("efficacy" OR "performance" OR "consistency")	120

[Table/Fig-2]: Data extraction table.

Quality assessment of included studies: The risk of bias of the included in-vitro studies was assessed using Quality Assessment Tool for In-vitro Studies (QUIN) tool. The criteria assessed by the tool were: Clearly stated aims/objectives; detailed explanation of sample size calculation; detailed explanation of sampling technique; details of comparison group; detailed explanation of methodology; details of the operator; randomisation; method of outcome measurement; details of outcome assessor; blinding; statistical analysis; and presentation of results. Each criterion was rated with the following possibilities: Adequately specified (score 2), inadequately specified (score 1), not specified (score 0), and not applicable. The studies were classified as high, medium, or low risk of bias (>70%=low risk of bias, 50% to 70%=medium risk of bias, and <50%=high risk of bias). Final score=(total score×100)/ (2×number of criteria applicable). Risk of bias was done for the 10 included studies. Of these, one study had low risk of bias and nine studies had medium risk of bias [Table/Fig-3,4].

S. No.	Study	Clearly stated aims/ objectives	Detailed explanation of sample size calculation	Detailed explanation of sample technique	Details of comparison group	Detailed explanation of methodology	Operator details	Randomisation	Method of measurement of outcome	Outcome assessor details	Blinding	Statistical analysis	Presentation of results	Score	Percentage {(score*100)/20}	Risk of bias
1	Jacob HB et al., 2015 [5]	2	1	0	1	2	0	NA	2	0	NA	2	2	12	60	Medium
2	de Villaumbrosia PG et al., 2016 [6]	2	1	0	2	2	0	NA	2	0	NA	2	2	13	65	Medium
3	Shimizu S et al., 2017 [15]	2	0	0	1	2	0	NA	2	0	NA	2	2	11	55	Medium
4	Mandelli F et al., 2017 [11]	2	0	0	2	2	0	NA	2	0	NA	2	2	12	60	Medium
5	Emir F et al., 2019 [9]	2	1	0	2	2	0	NA	2	0	NA	2	2	13	65	Medium
6	Lee SJ et al., 2020 [17]	2	1	0	2	2	0	NA	2	0	NA	2	2	13	65	Medium
7	Piedra-Cascón W et al., 2021 [8]	2	0	0	2	2	0	NA	2	0	NA	2	2	12	60	Medium
8	Baghani MT et al., 2021 [14]	2	1	0	2	2	2	NA	2	0	NA	2	2	15	75	Low
9	Pereira AL et al., 2022 [16]	2	1	0	2	2	0	NA	2	0	NA	2	2	13	65	Medium
10	Ellakany P et al., 2022 [18]	2	1	0	2	2	0	NA	2	0	NA	2	2	13	65	Medium

[Table/Fig-3]: Scoring sheet for Quality Assessment Tool for In-vitro Studies (QUIN) tool [5,6,8,9,11,14-18].



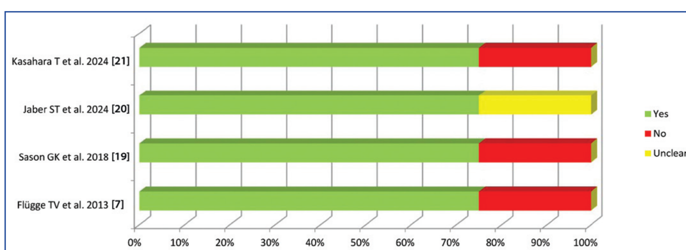
[Table/Fig-4]: Quality assessment of the included in-vitro studies [5,6,8,9,11,14-18].

The quality assessment of the analytical studies was done using JBI tool for analytical of cross-sectional studies. Each study was individually evaluated and assigned scores of 1 for "Yes" and "Not applicable", 0 for "No" and "Unclear" for each question. The cumulative score assigned to each question was divided by the maximum achievable score, i.e. eight for cross-sectional studies. If the scores were in the range of 0 to 0.3, the studies were considered as low quality; scores between 0.4 and 0.6 as moderate quality, whereas studies with scores between 0.7 and 1.0 were considered as high quality. The quality assessment for each study is presented in the below tables for each domain. A total of four studies were assessed and all were of high quality [Table/Fig-5,6].

Reference for the tool: https://jbi.global/critical-appraisal-tools.

Study	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Score	Quality
Flügge TV et al., 2013 [7]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6/8=0.75	High
Sason GK et al., 2018 [19]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6/8=0.75	High
Jaber ST et al., 2024 [20]	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes	6/8=0.75	High
Kasahara T et al., 2024 [21]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6/8=0.75	High

[Table/Fig-5]: Quality assessment the studies using JBI tool for analytical cross-sectional studies [7,19-21].



[Table/Fig-6]: Quality assessment graph for the studies with analytical cross-sectional study design [7,19-21].

RESULTS

Across all included studies, EOS consistently demonstrated superior accuracy, precision, and reproducibility compared with intraoral scanners, especially in complete-arch, implant, and laboratory workflows [Table/Fig-7]. Accuracy was influenced by scanner technology, with structured-light and high-end dental laboratory scanners outperforming laser-based and non-dental EOS. While intraoral scanners provided clinical advantages such as patient comfort and direct digital capture, their accuracy was more affected by intraoral conditions, stitching errors, and arch length.

S. no.	Study year	Material and Method	Sample size	Type of scanner	Accuracy of extraoral scanners	Reliability of Extraoral Scanners (EOS)	Efficacy of EOS	Type of Prosthesis	Results
1.	2013	In-vitro comparative study; models scanned repeatedly using iTero intraoral scanner, iTero extraoral digitisation, and a laboratory model scanner; precision assessed using 3D surface analysis and RMS deviation.	Intraoral scan- 10 Extraoral scan-10	Intraoral scanner- itero EOS- itero, D250	Extraoral scanning has the highest precision compared to intraoral scanning.	Not reported	Not reported	Maxillary and mandibular diagnostic cast	Qualitative result- 3D colour maps showed greater surface variability in intraoral scans; extraoral scanning showed smoother deviation patterns; model scanner demonstrated highest consistency Quantitative Results- Model scanner produced lowest RMS values (highest precision); extraoral iTero digitisation showed better precision than intraoral scans; intraoral scans had higher deviation values but remained clinically acceptable..
2.	2016	In-vitro comparison of 6 EOS (structured-light, LED, laser). Standardised reference model scanned repeatedly. Industrial scanner used for reference dataset. Accuracy assessed via 3D superimposition (trueness and precision).	EOS-10	IScan D101 (Imetric), Lava Scan ST (3M ESPE), and SmartOptics Activity 101 (Smart Optics) are structured light scanners; D640 (3Shape) and ZENO Scan S100 (Wieland) are laser scanners; and Renishaw Incise (Renishaw) is a contact scanner.	Of the six scanners, the ZENO Scan was the most accurate and precise for the majority of the variables measured.	Not reported	Not reported	A master die	Qualitative result-Structured-light scanners showed smoother, more uniform deviation maps; laser scanners showed greater localised errors; error distribution strongly dependent on scanning technology. Quantitative Results- Structured-light scanners showed highest trueness and precision (lowest RMS values). Laser scanners produced greater deviations. Precision varied significantly among scanners, with structured-light showing best repeatability.
3.	2021	In-vitro study using maxillary complete-arch model. Compared dental-specific E4 scanner vs. three non-dental structured-light scanners (Artec Space Spider, EinScan Pro 2X Plus, EinScan Pro HD). Ten scans per scanner. Trueness and precision evaluated with RMS deviation vs gold-standard reference model.	Non dental EOS -10 scan per scanner	A structured light dental laboratory scanner (Advaa Lab Scan; GC Europe) ND-1 (Space Spider; Artec), ND-2 (Capture Mini; Geomagic), and ND-3 (DAVID SLS3; David)	The accuracy values of the three non-dental structured light scanners that were tested fell outside of the ranges of the extraoral dental scanners claimed values.	Not reported	Not reported	Maxillary Diagnostic cast	Qualitative result- Dental scanner showed best accuracy and consistency. Non-dental scanners showed greater surface distortion, especially posteriorly. Artec closest to dental scanner; EinScan models showed more variability.) Quantitative Results- Trueness: E4 ≈ 15-20 µm; Artec ≈ 20-30 µm; EinScan HD ≈ 30-40 µm; EinScan 2X Plus ≈ 35-45 µm. Precision: E4 ≈ 10-15 µm; Artec ≈ 15-25 µm; EinScan HD ≈ 25-35 µm; EinScan 2X Plus ≈ 30-40 µm. Significant differences ($p<0.05$).
4.	2020	In-vitro comparison of intraoral (Trios 3) and EOS. Master cast scanned multiple times; STL files analysed for surface topography and precision. Surface comparison and RMS used to assess repeatability.	3 intraoral and 1 EOS	3 Intraoral scanners: CEREC Omnicam (Dentsply Sirona), TRIOS 3 (3shape A/S), and Carestream CS 3600 (Carestream Dental) and an EOS (Deluxe scanner; Open Technologies).	Attaining accuracy for partial-arch scans remains challenging for specific intraoral scanners. The Carestream scanner's trueness was outside the acceptable range.	Not reported	Not reported	Maxillary partially edentulous cast	Qualitative Results- EOS produced smoother surfaces, less noise, and better detail reproduction. IOS showed more variation and surface irregularities. EOS demonstrated most consistentscans.. Quantitative Results- Precision (RMS): EOS 6-12 µm; Trios 12-25 µm; iTero 20-35 µm. EOS significantly more precise. Surface deviation maps showed EOS with minimal surface distortion vs IOS.
5.	2017	In-vitro study using a prepared resin abutment. Compared intraoral (CEREC Omnicam, 3Shape TRIOS) vs extraoral (D810) scanner. Ten scans each. CAD crowns designed and evaluated for trueness, precision, marginal and internal fit.	10 scans per scanner	An EOS (D810) with Active Triangulation, An intraoral scanner (Cerec Omnicam) with Active Triangulation and an intraoral scanner with confocal laser (3Shape Trios, 3Shape; ICL).	Regarding trueness of scanning- the intraoral scanners were significantly different from the EOS for all values, with the exception of the margin value	Not reported	Not reported	Fixed dental prosthesis	Qualitative result- EOS produced more accurate, consistent CAD designs. IOS data showed more stitching errors and less uniform geometry. EOS-based crowns showed superior adaptation. Quantitative Results- Trueness: EOS 25-35 µm; IOS 40-60 µm. Precision: EOS 20-30 µm; IOS 35-50 µm. Marginal fit: EOS 40-50 µm; IOS 70-90 µm. Internal fit: EOS 60-80 µm; IOS 90-110 µm. Significant differences ($p<0.05$).
6.	2019	In-vitro comparison of eight extraoral lab scanners using a complete-arch reference model. Each scanner performed 5 scans. Evaluated trueness and precision via RMS deviation and 3D surface mapping.	10 scans per scanner	8 extraoral laboratory scanner - 7 Series, D640, D710, Activity 102, Tizian Smart-Scan, NeWay, InEOS, D2000	D2000 and NeWay were the systems with the best trueness and precision for full-arch scanning. Results from blue-light scanners were more accurate than those from white-light and laser scanners.	Not reported	Not reported	Arch shaped master model mimicking mandibular arch	Qualitative results- Wide variation among scanners. 3Shape D810, Zirkonzahn S600, and 3Shape E3 showed highest accuracy and repeatability. DW and CARES scanners showed larger deviations and less uniform scans. Quantitative Results- Trueness: Best: D810 (15-20 µm); Worst: CARES 7Series (50-60 µm). Precision: Best: D810 (10-15 µm); Worst: CARES 7Series (40-50 µm). Significant differences ($p<0.05$).

7.	2018	In-vivo study. 20 patients needing single crowns. Compared intraoral digital scanning (TRIOS) with extraoral scanning of casts from PVS impressions. Fit evaluated using silicone replica / microscopic measurement. Outcomes: marginal gap, internal gap, deviation, patient comfort.	10 patients 1 intraoral and 1 EOS	Intraoral - CS 3500 (Carestream dental) Extraoral-LAVA™ Scan ST Design system {3M™ ESPE})	When compared to the EOS, the intraoral scanner displayed less deviations and, therefore, greater precision.	Not reported	Not reported	Tooth preparation with endodontically treated mandibular 1st molar	Qualitative Results- IOS preferred by patients; faster & more comfortable; EOS affected by impression/cast distortions. IOS clinically more predictable. Quantitative Results- Marginal Gap: IOS 48-70 µm vs EOS 85-110 µm. Internal Fit: IOS 90-120 µm vs EOS 120-160 µm. IOS significantly more accurate ($p<0.05$).
8.	2022	In-vitro study. Master model with two implants at different inter-implant distances. Compared intraoral scanner (Trios 3) vs extraoral desktop scanner. 10-15 scans per condition. 3D deviation evaluated using best-fit alignment to a reference CMM scan. Outcomes: 3D deviation, RMS, angulation error.	10 scans per scanner	Intraoral scanner-(TRIOS; 3Shape A/S) EOS- (S600 ARTI Scan; Zirkonzahn)	While scanning with the device showed higher trueness for distances, the type and scanning techniques employed had no effect on the 3D deviations.	Not reported	Not reported	Mandibular model with 4 implants and abutments	Qualitative Results- EOS showed superior accuracy & repeatability. IOS affected by stitching errors and increased deviation with larger implant spacing. EOS less influenced by implant distance. Quantitative Results- 3D Trueness: IOS 35-60 µm; EOS 10-25 µm. Precision: IOS 20-35 µm; EOS 8-15 µm. Angular deviation lower in EOS. Inter-implant distance increased deviations more in IOS.
9.	2024	In-vivo + in-vitro comparative study of IOS vs EOS. 20 dental arches scanned directly with IOS and indirectly using extraoral scanning of stone models. Repeated scans for precision. Linear and 3D measurements analysed using digital software. Outcomes: trueness, precision, ICC.	20 patients	Medit intraoral scanner (i700; Medit, Seoul, Korea) 3D desktop scanner (T710; Medit)	Both direct and indirect scanning techniques are accurate and reliable for digital model preparation and can be considered an alternative to traditional plaster models.	Both direct and indirect scanning techniques are accurate and reliable for digital model preparation and can be considered an alternative to traditional plaster models.	Not reported	Patients with malocclusion	Qualitative Results- Both scanners produced clinically accurate models. EOS showed better trueness and consistency; IOS showed small distortions in posterior regions and long spans. Both systems demonstrated excellent reliability, with EOS less operator-dependent. Quantitative Results- Accuracy: Deviations between IOS & EOS: 0.05-0.40 µm; EOS more accurate (lower deviations). 3D RMS: IOS 60-120 µm; EOS 30-70 µm. Reliability: ICC 0.92-0.98 (IOS), 0.95-0.99 (EOS).
10.	2022	In-vitro study using a phantom dental cast. Impressions made in polyether, poured into stone. Scanned with 2 IOS (Trios 3, DW) and 2 EOS (Zirkonzahn S600 ARTI, Ceramill Map 600). Tooth dimensions (canine, premolar, molar) measured on digital scans (Geomagic) and compared with reference stereomicroscopic measurements.	4 scanners	Intraoral Scanners (IOS):3Shape Trios 3, Dental Wings (DW) (presumably DW IOS) EOS (EOS): Zirkonzahn S600 ARTI (ZK),Ceramill Map 600 (Amann Girrbach, AG)	There was no statistically significant difference in the overall dimensional discrepancies among the four scanners.	Not reported	Not reported	A phantom cast	Qualitative Results-. Scanner performance influenced by tooth geometry; smooth / regular surfaces (canine) had different error profiles compared to others. Both IOS and EOS showed clinically similar accuracy overall. Quantitative Results- ANOVA: No overall significant difference among 4 scanners ($p=0.969$). Canine: significant difference ($p=0.025$). Premolars & Molars: not significant. EOS discrepancy ≤0.01 mm for canines/molars; DW showed the highest error in these teeth.
11.	2024	In-vivo study with 3 subjects (6 auricles). Compared: (1) EOS (Artec Spider) without reference board, (2) same scanner with reference board, (3) intraoral scanner (Trios 3), and (4) conventional facial impression (alginate cast scanned with lab scanner). Measured via STL superimposition, RMS error, and auricle dimensions (caliper vs scan).	Three patients - two men and one woman	Extraoral handheld 3D optical scanner (Spider; Artec Spider, Senningerberg, Luxembourg) and an IOS (Trios3, 3Shape, Copenhagen, Denmark	Significant differences in auricular sizes and variations in the accuracy of the scanning methods were observed, with discrepancies within 3 mm in length. However, these discrepancies were considered clinically acceptable.	Not reported	Not reported	Auricular Prosthesis	Qualitative Results- Back, margins, and dorsal auricle surfaces showed largest deviations. Deep inner curves/undercuts were challenging to scan. Reference board improved alignment variably. Optical scans considered clinically acceptable. Quantitative Results- RMS Error: Spider/-board vs F-impression=1.7-2.4 mm; Optical vs optical (Spider vs IOS)=~0.5-1.0 mm; Board reduced error by 0.59-1.04 mm. Auricle length overestimated by up to ~4.6 mm, width up to ~7.7 mm, height underestimated. No major statistical difference in size ($p>0.05$ for many).

12.	2021	In-vitro study using a master complete-arch model. Compared intraoral Trios 3 vs. extraoral Einscan-Pro 2X Plus. Ten scans per scanner. Evaluated trueness and precision via RMS deviation compared with industrial reference model.	10 casts by 2 intraoral and 2 EOS	Intraoral scanner -Trios 3shape (3S; 3Shape Trios 3 A/S 2018, Copenhagen, Denmark (DW; Dental Wings Inc., Montreal QC, Canada). EOS- 3 Zirkhonzahn (ZK; S600 ARTI, Zirkonzahn Deutschland GmbH, Neuler, Germany) and Amann Girrbach (AG; Ceramill Map 600, Amann Girrbach GmbH, Pforzheim, Germany)	The IOSs and EOS had similar accuracy except in canines where EOS performed better. As with the canine, the smoothness and regularity of the tooth surfaces have an impact on scanning accuracy.	Not reported	Not reported	Maxillary and mandibular diagnostic cast.	Qualitative Results- EOS showed superior consistency and accuracy, especially in posterior arch. IOS demonstrated increased stitching errors and less uniform surface reproduction. EOS was more reliable for complete-arch prosthodontic workflows. Quantitative Results- EOS trueness: ~35-45 µm; IOS: ~70-90 µm. EOS precision: ~30-40 µm; IOS: ~60-80 µm. EOS significantly more accurate and precise ($p<0.05$).
13.	2017	In-vitro study using a sand-blasted titanium single-tooth abutment model. Reference model scanned by industrial scanner to get a gold-standard STL. Seven laboratory EOS each scanned the model 10 times. Data compared in Geomagic Qualify (trueness & precision).	10 scans per scanner	7 EOS are- D640, D700, Sinergia , Aadva, DScan, Zfx , Conc Sc Top.	Accuracy was evaluated calculating trueness and precision. Two laboratory scanners (Aadva, Zfx Evolution) were significantly better that other tested scanners.	Not reported	Not reported	Titanium Model	Qualitative Results- Aadva and Zfx Evolution were the most accurate and repeatable. Some scanners (Sinergia, Concept Top) showed larger deviations. Standardised model recommended for performance comparison. Quantitative Results- Trueness: Aadva 7.7 µm; Zfx 9.2 µm; D640 18.1 µm; D700 12.8 µm; Sinergia 31.1 µm; DScan3 15.6 µm; Concept Top 28.6 µm ($p<0.0005$). Precision: Aadva 4.0 µm; Zfx 5.1 µm; D640 12.7 µm; D700 11.0 µm; Sinergia 16.3 µm; DScan3 9.5 µm; Concept Top 19.5 µm ($p<0.0005$).
14.	2015	In-vitro study using dry human skull. Compared intraoral Lythos scanner vs. extraoral Ortho Insight 3D scanner. Multiple repeated scans for reliability; validity assessed by comparing linear measurements to gold-standard reference model. ICC and mean errors calculated.	15 samples 2 scans per scanner	One extraoral {Ortho Insight 3D™ (Motionview Software, Hixson, TN/USA)} and two intraoral {ITero™ (Align Technologies, San Jose, CA/USA) and Lythos™ (Ormco Corp., Orange, CA/USA)} scanners		While all the scanners produced reliable measures Ortho Insight 3D systematically underestimated arch length and canine height	Not reported	Model of mandible	Qualitative result- Both scanners reliable and valid. EOS provided more uniform surface detail; intraoral scanner slightly less consistent in complex areas. Differences minimal and clinically insignificant. Quantitative Results- High reliability for both scanners (ICC > 0.90). Measurement errors ≤ 0.30 mm. EOS slightly more accurate for width measurements; intraoral scanner showed acceptable but slightly higher variability.

[Table/Fig-7]: Details of the included studies.

EOS showed excellent reliability, minimal operator dependency, and more uniform data capture across repeated scans.

Qualitative Results

EOS have consistently been shown to generate smoother and more homogeneous surface reconstructions with fewer cumulative stitching errors than intraoral scanners, owing to the stable laboratory environment and controlled scanning conditions. Among the available technologies, structured-light EOS demonstrate the most uniform and predictable deviation patterns, whereas laser-based scanners tend to exhibit localised inaccuracies, particularly in areas with complex geometry. Evidence further indicates that dental-specific EOS outperform non-dental structured-light scanners, which are more prone to distortion, especially in posterior regions and full-arch scans. Owing to their higher stability and resolution, EOS are regarded as more reliable for long-span restorations, complete-arch digitisation, and implant-level scans, where maintaining geometric consistency is critical despite increasing complexity. In prosthodontic applications, CAD restorations fabricated from EOS data have been reported to exhibit superior marginal and internal fit compared with restorations derived from intraoral scanning data. Across the existing literature, EOS demonstrate high repeatability and minimal operator dependency, reflecting strong reliability. Overall, qualitative evidence strongly favours EOS for applications requiring high precision and consistency, particularly in prosthodontic and laboratory-based workflows.

Quantitative Results

Quantitative assessments of accuracy consistently demonstrate that EOS achieve superior trueness and precision compared with intraoral scanners (IOS). Reported trueness values for EOS generally range from approximately 7 to 45 µm, while precision values range from 4 to 40 µm, depending on scanner type and scanning technology, as demonstrated in controlled in-vitro and complete-arch analyses [5-7,9,11,14,17]. In contrast, IOS systems typically exhibit higher deviations, with trueness values reported between 35 and 90 µm and precision values ranging from 20 to 80 µm, particularly in full-arch and long-span scans, reflecting cumulative stitching errors and intraoral environmental limitations [7,14,17-20]. Consequently, EOS consistently achieve significantly lower Root Mean Square (RMS) deviation values, indicating superior overall accuracy [6,9,14,17].

With respect to prosthesis fit, restorations fabricated from EOS data demonstrate improved marginal and internal adaptation. Marginal fit values for EOS-derived restorations have been reported at approximately 40-50 µm in-vitro and 85-110 µm in cast-dependent workflows, whereas IOS-based restorations typically show marginal gaps in the range of 48-70 µm [11,15,19,18]. Similarly, internal fit measurements favour EOS, with reported values of approximately 60-80 µm, compared with 90-120 µm for IOS-based restorations, indicating more uniform internal adaptation when laboratory scanners are used [11,15,18].

In full-arch and implant-level scanning, EOS demonstrates markedly better three-dimensional trueness and precision. Reported 3D trueness values for EOS range from 10 to 25 µm, with precision values of approximately 8-15 µm, whereas IOS show higher deviations, with trueness values of 35-60 µm and precision values of 20-35 µm, particularly as inter-implant distance increases [7,14,16,17]. EOS also exhibit lower angular deviations and a reduced increase in error with increasing implant span, highlighting their suitability for complex implant rehabilitations [7,16].

Reliability analyses further support the consistency of EOS, with Intraclass Correlation Coefficient (ICC) values commonly reported between 0.95 and 0.99, compared with 0.92 to 0.98 for IOS, indicating higher repeatability and reduced operator influence for extraoral scanning workflows [5,20,17]. Additionally, when comparing dental-specific EOS with non-dental structured-light scanners, dental EOS demonstrate significantly superior trueness, typically in the range of 15-20 µm, whereas non-dental scanners exhibit higher deviations of approximately 30-45 µm, with statistically significant differences reported ($p<0.05$) [8]. Collectively, these findings indicate that EOS provides superior accuracy, prosthetic fit, and reliability, particularly for prosthodontic and laboratory-based applications requiring high precision.

DISCUSSION

The aim of the present systematic review was to evaluate the accuracy, efficacy, and reliability of EOS across different dental and prosthodontic applications, and the findings largely align with the existing body of literature indicating that EOS demonstrate high accuracy and reproducibility under controlled conditions [1,2]. Accuracy, defined as the ability of a scan to faithfully represent the true geometry of the scanned object, is critical for prosthodontic fabrication, orthodontic assessment, and implant planning, and is commonly evaluated through trueness and precision metrics [2,3]. The quantitative results of this review, showing superior trueness and precision for EOS compared with intraoral systems, are consistent with earlier investigations reporting lower deviation values and improved repeatability for laboratory-based scanning [1,4,7].

Jacob HB et al. demonstrated that EOS exhibit significantly higher reliability and validity than intraoral scanners, attributing these findings to stable scanning environments and reduced operator- and patient-related variables, which supports the lower RMS values observed in the present quantitative synthesis [5]. Similarly, Flügge TV et al., reported significantly lower deviation values for extraoral digitisation compared with intraoral scanning in complete-arch analyses, a finding that directly corresponds with the superior full-arch trueness and precision identified in this review [7]. These findings reinforce the concept that EOS serve as a reference standard for digital model acquisition, particularly in orthodontic and prosthodontic workflows [5,7].

The present review also corroborates findings by de Villaumbrosia PG et al., who demonstrated that scanner performance varies substantially depending on scanning technology, with structured-light EOS consistently showing superior trueness and precision compared with laser-based systems [6]. This technological influence is further supported by Emir F and Ayyıldız S. who reported wide variability in accuracy among eight EOS, emphasising that hardware design, optical principles, and reconstruction algorithms play a decisive role in scan quality [9]. Accordingly, the quantitative results of this review align with the literature in identifying structured-light scanning algorithms as the most predictable and reliable for dental applications [3,7].

In agreement with Piedra-Cascón W et al., this review found that dental-specific EOS outperform non-dental structured-light scanners, particularly in posterior regions and full-arch scans, despite some industrial scanners demonstrating clinically acceptable accuracy [8]. These findings highlight that while non-dental scanners may offer cost advantages, dental-specific calibration, resolution, and reconstruction algorithms remain critical for achieving optimal accuracy in complex dental geometries [5]. Mandelli F et al., further supported this observation by demonstrating superior accuracy of laboratory scanners in single-tooth and abutment scans, reinforcing the suitability of dental EOS for precision-dependent prosthodontic tasks [11].

With respect to CAD-CAM workflows, the present findings are in accordance with Shimizu S et al., who reported that restorations designed from EOS data exhibited stable marginal and internal adaptation, particularly for fixed dental prostheses [15]. Although Shimizu S et al., found both intraoral and EOS to be clinically acceptable, the consistently lower variability associated with EOS mirrors the improved prosthesis fit identified in the quantitative analysis of this review [15]. Similarly, Ellakany P et al., observed that EOS produced more consistent digital impressions compared with intraoral systems across different CAD/CAM technologies, supporting the reliability outcomes reported here [18].

In-vivo evidence further substantiates these conclusions, as Sason et al. demonstrated that EOS achieved superior dimensional accuracy and repeatability compared with intraoral scanning in clinical settings, particularly for full-arch impressions [19]. Pereira AL et al., also reported that EOS exhibited lower three-dimensional deviations and reduced error accumulation with increasing inter-implant distance, findings that are consistent with the implant-level accuracy advantages observed in this review [16]. These results contrast with some intraoral scanner studies reporting acceptable accuracy for short-span cases, indicating that EOS maintain their advantage primarily in complex and long-span applications [8,9].

Regarding reliability, the high ICCs reported across studies included in this review are consistent with findings by Jaber ST et al., who demonstrated strong repeatability and dimensional consistency of EOS-derived digital models compared with intraoral scans and conventional casts [20]. Lee SJ et al., similarly reported smoother surface topography and higher precision for EOS, reinforcing their reduced susceptibility to operator influence and environmental variability [17]. Although Kasahara T et al., focused on facial and auricular scanning, their findings further support the broader reliability of extraoral optical scanning systems under controlled conditions [21].

Overall, the quantitative findings of this systematic review are largely in agreement with the existing literature, confirming that EOS-particularly structured-light dental laboratory scanners- offer superior accuracy, consistency, and reliability compared with intraoral scanners in prosthodontic, orthodontic, and implant applications. Minor contradictions across studies appear to be primarily attributable to differences in scanner technology, evaluation protocols, and clinical complexity rather than fundamental limitations of extraoral scanning itself. These findings collectively support the role of EOS as a cornerstone of precision-driven digital dentistry workflows.

CONCLUSION(S)

The EOS represents a major advancement in digital dentistry, offering high accuracy, strong precision, and reliable reproducibility across prosthodontic, orthodontic, and restorative applications. Their ability to produce consistent, detailed digital models enhances both clinical and laboratory workflows while improving patient comfort and reducing chairside time. Although limitations such as cost and required operator training persist, ongoing technological developments are expected to improve accessibility and performance. Overall, the accuracy, efficacy, and reliability of EOS make them an essential tool in modern digital dental practice and support the continued shift toward fully digital, patient-centered care.

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