Annals of Orthodontics and Periodontics Specialty
Volume 3, Page No: 32-42
Available Online at: aopsj.com

Review Article

Comparison of Conventional and Digital Techniques for Evaluating CAD/CAM Crown Margins

Amrutha Shenoy[1], Deepak Nallaswamy[1], Subhabrata Maiti[1]*

1. Department of Prosthodontics and Implantology Saveetha Dental College and Hospitals Saveetha Institute of Medical and Technical Sciences Saveetha University Chennai600077, Tamilnadu, India.

***E-mail** ✉ drsubhoprostho@gmail.com

Abstract

With the advancement of CAD/CAM technology, accurate digital data is crucial for the long-term success of prosthetics. The present study aimed to find and comprehensively review the literature on the digitization process of CAD/CAM crowns using CBCT and compare it with the results obtained using standard scanners to determine fit. The PRISMA guidelines were used. “Does the scanning technique (I) provide better accuracy and marginal fit (O) in teeth that require full veneer crowns (P) compared with the routine digital methods of fabrication (C)?” were the keywords. A thorough electronic search was conducted between 2015 and January 2023. All studies that compared the fit of prostheses fabricated with intraoral scanners and CBCT were included. An electronic database search identified 260 articles. Four studies were included to answer the research question. The marginal differences of digitally created crowns using CBCT were examined in all four studies. The marginal fit of crowns did not show any statistically significant differences. There is not much research comparing the fit of crowns made with intraoral, extraoral, and CBCT scanners. According to the current systematic review, high-quality trials are needed to evaluate the precision and fit of crowns and prostheses made with CBCT scans as intra-oral scanners.

Key words: Cone beam computed tomography, Intra-oral scanners, Extraoral scanners, CAD/CAM dentistry, Systematic review

How to cite this article: Shenoy A, Nallaswamy D, Maiti S. Comparison of Conventional and Digital Techniques for Evaluating CAD/CAM Crown Margins. Ann Orthod Periodontics Spec. 2023;3:32-42.

Received: 01 June 2023; **Revised:** 30 August 2023; **Accepted:** 10 September 2023

Introduction

Dental professionals are increasingly using digitalization since it has been shown to have numerous benefits over conventional techniques [1-3]. According to certain research, crowns built using 3D printing have better marginal fits than those made with conventional or CAD/CAM milling procedures. These approaches have been demonstrated to enhance the fit and accuracy of dental prostheses [4-8].

Prefabricated blocks and blanks are now easily accessible, and the usage of digitally generated models has grown in popularity as a treatment planning technique [9]. Scanning a gypsum cast using a scanner is one method of creating such a model; nevertheless, the impressions may cause discomfort for the patient, a gag response, pain during retraction, and distortion due to various disinfection procedures [10, 11]. Intraoral scanning is another option, although it's not always accessible and is costly [12-14]. Furthermore, DICOM pictures that can be transformed into standard tessellation language (STL) files can also be used to build them. Then, using these models, patient-specific guides and implant-supported fixed dental prostheses (FDPs) can be made without the need for traditional impressions [14-16]. It has been proposed that superimposing CBCT image files and STL files is a dependable and effective technique that is also time and money-efficient and has a high patient approval rate [16-18].

For full coverage restorations to be clinically successful, the marginal fit is essential [19, 20]. Crown misfits can have a detrimental effect on the teeth and soft tissue around them [19, 21, 22]. Although the acceptable marginal fit is not yet established, some researchers recommend that for CAD-CAM restorations, the gap should not be greater than 100 mm [23, 24]. The introduction of technology like CT and MRI has given clinicians access to new diagnostic tools and methods for planning and fabricating prosthesis surgeries. Cone beam CT (CBCT) is one of these technologies that allows for 3D high-resolution imaging with minimal radiation dosages to diagnose and treat patients. Without the need for intraoral imprints or stone casts, digital data can also be utilized to reconstruct 3D pictures and produce patient-specific abutments using a standard tessellation language (STL) file exported from interactive software. But as of right now, no published study contrasts the marginal difference between crowns made with digital scanning data and crowns made with CBCT data [25-27]. This systematic evaluation aims to ascertain whether, in comparison to commonly used digital approaches, the utilization of CBCT scans for full coverage restoration fabrication can produce superior marginal fit. The null hypothesis states that restorations made using digital and CBCT scanning techniques have comparable internal and marginal discrepancies.

Materials and Methods

This review was done following PRISMA guidelines. The keywords were defined based on one PICO (population [P], intervention [I], comparison [C], and outcome [O]) questions: first, “In teeth requiring complete coverage restorations(P), does the digital scanning technique (I) provide better accuracy, marginal fit and internal adaptation (O) compared with the conventional digital methods of fabrication (C).

A comprehensive search was conducted from 2015 to January 2023 in several databases, including PubMed's Medline, Elsevier's Scopus, Cochrane's Controlled Register of Trials (CENTRAL), Science Direct, Europe PMC, LILACS, Google Scholar, and WILEY online library. In addition, a hand search was completed on the reference list of included studies. In addition, a direct search was performed on the bibliographies of all reviewed articles and the websites of the prestigious prosthodontics journals.

PUBMED search strategy

An advanced search was conducted using the PubMed search engine with the following combination of keywords:

1. *Occlusal and esthetic parameters*
    - Occlusal discrepancies, occlusal disharmony, esthetic outcomes, occlusal fit, occlusal misfit, marginal fit, marginal adaptation, T-scan, pink esthetic score, patient satisfaction, quality of life, periodontal index, gingival index.

2. *Imaging and scanning technologies*
    - CBCT, cone beam computed tomography, C-arm CT, cone beam CT, digital volume tomography, field of view, voxel, DICOM, Carestream, imaging software, and intraoral scanner.

3. *Crown fabrication and temporization*
    - Acrylic temporary crowns, temporization, provisional restoration, PMMA, polymethylmethacrylate, crown fabrication, CAD/CAM, additive manufacturing, subtractive manufacturing, 3D printing, 3D printed crowns, milling, digitalization, direct digitalization, indirect digitalization, computer-aided design, computer-aided manufacturing.

4. *Patient-specific factors*

- Patients undergoing full mouth rehabilitation, full mouth rehabilitation, FMR, reduced vertical dimension, reduced vertical height, decreased vertical dimension, fixed prostheses, fixed prostheses, fixed dental prostheses, crowns, and fixed partial dentures.

Cochrane database search

An advanced search was performed in the Cochrane database, yielding a total of 9 relevant studies.

Sciencedirect search strategy

The ScienceDirect search engine was utilized with an advanced search using the following keywords:

- (CBCT OR cone beam computed tomography) AND (intraoral scanners OR extraoral scanner) AND (fixed prosthesis OR crowns).

This comprehensive search strategy ensures a thorough exploration of the literature related to occlusal discrepancies, imaging technologies, crown fabrication methods, and patient-specific factors in full-mouth rehabilitation.

Search results and study selection process

The search yielded a total of 58 studies from the initial database. Additionally, a search in the Europe PMC database produced 1 relevant result, while the Lilac database did not yield any applicable studies. A search in Google Scholar resulted in 62 studies.

Study screening and assessment

Two independent reviewers, A.S. and S.M., conducted a standardized and unblinded assessment of the eligible studies. The screening process was carried out in two stages:

1. *First Round:* Titles and abstracts of the publications retrieved from the database search were screened for relevance.
2. *Second Round:* The full text of all articles deemed eligible from the first round was thoroughly reviewed. Only studies meeting the predefined criteria were included in the systematic review and considered for data extraction.

Inclusion criteria

Studies were included if they met the following criteria:

- Randomized controlled clinical trials
- Case-control studies
- Cohort studies
- Ex-vivo studies
- In vitro studies
- Human studies
- Studies where prostheses were fabricated using CBCT (cone beam computed tomography)
- Studies published exclusively in English.

Exclusion criteria **(Table 1)**

Studies were excluded based on the following:

- Use of a combination of techniques for data acquisition in prosthesis fabrication
- Animal studies
- Literature reviews
- Articles published in languages other than English
- Ongoing studies without published results.

This rigorous selection process ensured that only high-quality and relevant studies were included in the systematic review.

Table 1. Characteristics of excluded studies

S/No	Study	Reason for exclusion
1.	Liu *et al*. (2017)	Merging of CBCT and intra-oral scans without comparison between the two.
2.	DuVall. *et al*. (2020)	CBCT is used for implant treatment planning after prosthesis fabrication.
3.	Salem *et al*. (2016)	Fit accuracy of CAD/CAM crowns was assessed using CBCT, not for fabrication.
4.	Hafez *et al*. (2019)	The internal fit of two CAD/CAM systems was evaluated using CBCT.
5.	Moaty *et al*. (2018)	Fracture resistance and fit were evaluated using CBCT; the abstract did not match the search criteria.
6.	Akmal *et al*. (2020)	Marginal gap evaluated using CBCT.
7.	Evans *et al*. (2018)	CBCT and CAD/CAM are used for the fabrication of root-analog dental implants.
8.	De-Azevedo-Vaz *et al*. (2020)	CBCT is used to evaluate the misfit of implant abutment joint, not for fabrication.
9.	Decani *et al*. (2018)	CBCT is used to evaluate the internal fit of different groups, not for fabrication.
10.	Noharet *et al*. (2019)	CBCT and CAD/CAM are used for preserving the emergence profile and implant placement, not for interim crown fabrication.
11.	Polara *et al*. (2020)	CBCT is used for the fabrication of interim screw-retained crowns, with chair time comparison to the indirect-direct method.

The characteristics of the studies included were analyzed using their data. The following characteristics were included:

- Author and year of study
- Study design
- Study setting
- The country where the studies were done
- Sample size
- Study groups: intervention and control
- Outcome assessment: variables assessed and method of evaluation

Tables 2 and 3 list the variables that were noted. A detailed analysis of the study's variables' mean values and statistical significance was conducted.

The CBCT group and the digital group were the two groups into which the investigations were separated according to the fabrication process. The groups' differences in the marginal were the main outcomes that were measured. Based on the SMD, qualitative assessments were carried out independently for the in-vitro investigations. The mean difference (MD) and its standard error were calculated for the marginal fit analysis. To ascertain if the data were normally distributed, the Shapiro-Wilks and Kolmogorov-Smirnov tests were employed [28]. Nevertheless, one study failed to obtain homoscedasticity and a normal distribution of within-group data [29]. The uniformity of the data was not explained in the other two trials. Because the sample size was limited, unpaired tests were used, which might have further affected the outcomes. Since there is presently no appropriate technique for in-vitro investigations, an evaluation of the risk of bias for the included studies was not carried out [30].

Results and Discussion

A comprehensive search of electronic databases was carried out, including ScienceDirect (58 studies), Google Scholar (62 studies), Cochrane Library (9 studies), and PubMed (130 studies). The databases of the LILACS and WILEY online libraries did not contain any studies, and EuropePMC provided one. 24 studies were found after duplicates were eliminated and the titles were examined. Nine of them were not included in the systematic review. The remaining 15 studies' full-text papers were acquired, and any further research was added to their bibliographies. In the end, four papers satisfied the proposed research's inclusion and exclusion criteria **(Figure 1)**.

Standard mean values of the marginal fit of crowns were used to evaluate the results, and characteristics of the included studies were described **(Tables 2 and 3)**. Three groups were compared by Kale *et al*. [31]: crowns made using CBCT scans, crowns made with CBCT and lab scanners, and crowns made with lab scanners alone (control group). Using a zoom microscope, the vertical marginal disagreement was assessed. They found that using simply CBCT or laboratory scanners, as opposed to a combination of both, produced a better marginal fit. Nonetheless, there was a statistically significant difference ($P < 0.001$) between the CBCT and Laboratory scanning groups.

Another study by Kim *et al*. [32, 33] examined two groups: crowns made with intraoral scanners and crowns made with CBCT. A digital microscope was used to assess the marginal gap, and the replica approach was used using light-body PVS materials. The measured errors fell within the clinically allowed range of 177-400 microns, and they found that greater resolution CBCT could produce better results, which would help with the acquisition of digital models and the production of prostheses.

Şeker *et al*. [11] examined the marginal fit of crowns made with varying voxel (0.3, 0.2, and 0.125) imaging resolutions with extraoral laser scanners. Using a zoom stereo microscope, the vertical marginal disparity was seen at four different crown locations. Although CBCt scans using 0.125 voxel images produced superior findings, they used extraoral laser scanners to observe better results. In their comparison of two CBCT systems with intraoral (IOS) and extraoral (EOS) scanners, Kauling *et al*. [28] examined the precision and fit of the crowns made with 3D analysis. Significant differences were seen in the marginal fit of CBCT1, CBCT2, IOS, and EOS. Although not as good as the scanners, the marginal fit of CBCT1 AND CBCT2 was within the range of clinically acceptable.

Table 2. Characteristics of included studies

Author and Year	Study design	Study setting	Country	Sample size		Study groups		Outcome assessment	
						Intervention	Control	Variables assessed	Evaluation method
Kale *et al.* (2019)	Ex-Vivo study	University setting	Turkey	3 groups	N= 58 single crowns, 16 in each group.	Group 1: N=16 crowns fabricated using CBCT scan (iCAT) Group 2: N = 16 Crowns fabricated using Cbct, PU cast, and 3d laboratory scanner (PU3DLab) (modified. CAD/CAM production workflow)	Group 3: N = 16 Crowns fabricated using 3d laboratory scanner (D900, 3Shape)	i) Vertical marginal discrepancy using a zoom microscope.	i) Marginal gap, measurements done at 384 points
Kim *et al.* (2020)	In-vitro study	University setting	Korea	2 groups	N = 16 single crowns in each group.	Group 1: N = 16 impressions of 16 patients, crowns fabricated from CBCT scan (RAYSCAN)	Group 2: N=16 control group, crowns fabricated using an intra-oral scanner (CS3600)	i) Marginal gaps ii) Internal gaps iii) Total gaps using a digital microscope.	i) Replica technique used to measure accuracy using light body PVS materials.

	Kauling *et al.* (2019)	**Seker *et al.* (2015)**
	In-vitro study	Ex-Vivo study
	University setting	University setting
	Germany	Turkey
	4 groups N = 12 in each group	4 groups N = 9 per group
	Group 1: CBCT1 (CS9300) Group 2: CBCT 2 (CS8100) Group 3: extraoral scanner (Ceramill Map 400)	Group 1: 0.3 Voxel CBCT image Group 2: 0.2 voxel CBCT image Group 3: 0.125 voxel CBCT image (iCAT scan)
	Group 4: Intra-oral scanner (CS3600)	Group 4: N = 9 control group, crown fabricated using an extra-oral laser scanner (D900 3Shape)
	i) Accuracy of the dataset ii) Analysis of fit	i) Vertical marginal discrepancy using a zoom stereo microscope.
	i) Accuracy of dataset quality using Geomagic superimposition software ii) Fit evaluated using the replica technique.	i) Vertical marginal discrepancy checked at 4 sites per crown.

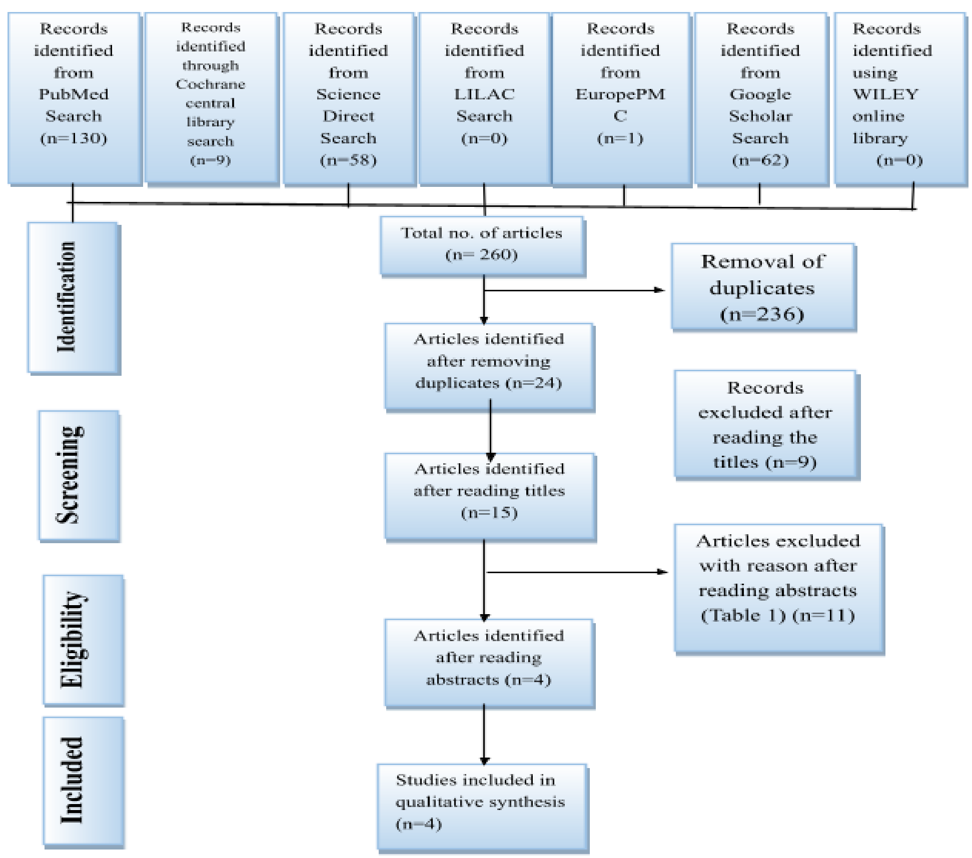

Figure 1. PRISMA flowchart for article selection

Table 3. General information on the results of included studies

S/No	Reference	Method of fabrication of prosthesis	Results obtained	Overall conclusion
1	**Kale *et al.* [29]**	The Maxillary left first molar was extracted, prepared, and then digitized using a 3D laboratory scanner. A CBCT scan was performed, and then a crown was fabricated. Milled crowns are sintered and fabricated according to the manufacturer's instructions.	VMD: Control group: VMD = 41um CBCT scan: VMD = 44um PU3DLab: VMD = 60um The statistical difference was seen between the CBCT group and the PU3DLab group (P < 0.001) No statistical difference between the control and CBCT scan groups (P =	The marginal fit of crowns using a 3D laboratory scanner and through CBCT was better than crowns fabricated by using the workflow that combined CBCT, PU cast, and 3d laboratory scanner.
2	**Kim *et al.* [33]**	16 impressions for single crown restorations were scanned using CBCT, and scanning data were converted to STL. Files. Stone models were scanned using intra-oral scanners. Converted stl. Files used to fabricate single crowns.	The root mean square value of CBCT and IOS ranged from 41 um- 126 um (mean = 60.2 um) Marginal gap: mean = 132.96 um Internal gap: mean = 255.88 um	Measured errors were within the clinically permitted range (177-400 um). High-resolution CBCT could be widely used for digital model acquisition and prosthesis fabrication.
3	**Seker *et al.* [11]**	Crown preparation was done on the extracted premolar, the tooth was scanned using a 3D extra oral scanner (D900, 3shape) and CBCT (iCAT system) at different voxel resolutions.	The marginal gap using an extraoral laser was lower than those of crowns fabricated with CBCT scans. (P < 0.001) CBCT images were used when compared to 0.125 voxel images. (P < 0.001)	Crowns fabricated with laser scanners yielded better results than CBCT scans. Only CBCT scans with 0.125 voxels gave good results.
4	**Kauling *et al.* [11, 28]**	The accuracy of 3D samples was assessed by best-fit superimposition (Geomagic software). The marginal fit was assessed using the replica technique using heavy body silicone. Fit was evaluated using Optimas 6.5 software.	IOS group: (-0.011 ± 0.007 mm/-0.010 ± 0.003 mm) CBCT 1 group: (-0.046 ± 0.008 mm/0.093 ± 0.004 mm) CBCT 2 (-0.049 ± 0.030 mm/0.072 ± 0.015 mm) EOS (-0.023 ± 0.007 mm/0.028 ± 0.007 mm) The marginal fit was as follows: IOS (0.056 ± 0.022 mm) CBCT 1 (0.096 ± 0.034 mm) CBCT 2 (0.068 ± 0.026 mm) EOS (0.051 ± 0.017 mm)	There were statistical differences in the marginal fit between the EOS, IOS, CBCT 1, and CBCT 2 groups. The fit of the CBCT 1 and CBCT 2 groups was deemed to be clinically acceptable, however, they were not as good as the EOS and IOS groups.

An updated study was necessary since earlier research and reviews produced contradictory results regarding the internal and marginal adaption of full coverage restorations made utilizing various techniques. Comparing the marginal fit of crowns made with CBCT scans to digital intraoral and extraoral scanners is the primary goal of this review. An IOS can be used for direct digitization of data or an EOS or CBCT image can be used for indirect digitization. To create a gypsum cast, indirect digitalization necessitates a traditional imprint using elastomeric materials, which could result in several production problems. The review's external validity may be limited because all of the studies it analyzed were carried out in Eastern nations, and there isn't much evidence from Western nations.

Marginal fit

As of right now, there is no consensus regarding the permissible amount of marginal discrepancy in dental restorations. A distance of 200 micrometers or less is recommended by some authors, while others have suggested a threshold of 120 micrometers or less [11, 28, 33]. Within this range, the majority of the analyzed studies reported marginal gap values. All of the included studies used 2D analysis to assess the marginal fit, either with a digital microscope or a zoom stereo microscope. However, this approach only permits a small number of measuring points and sections, which might not give a complete picture of the crown's overall fit. Furthermore, several studies—like those by Ediz Kale and Emre Seker *et al*.—were carried out by a single operator using a zoom stereo microscope and real-time measuring software, which may have injected bias into the findings. By providing multiple-point measurements, alternative techniques like the triple-scan procedure or 3D analysis utilizing micro-computed tomography may yield more accurate and trustworthy results. As a result, the included research in this review might be regarded as having poor reliability and validity.

Cone beam computed tomography

i-CAT, RAYSCAN, and Carestream dental imaging were among the CBCT scanner types that were used in the study. According to one study, when used to virtual 3D tooth models created from CBCT scans, the size of the voxel used in the scan significantly affected the marginal integrity of crowns made using CAD and CAM. The accuracy of two generations of CBCT scanners was assessed in another study, and it was discovered that the second generation outperformed the first [34-36]. To balance the hazards of radiation exposure with optimal outcomes, practitioners should be aware of the scanning parameters. Investigating the impact of all coexisting characteristics on the accuracy of virtual cast reconstruction will require more work.

CAD/CAM workflow: (Scanning and CAM process)

In this review, two studies used intraoral scanners by Carestream Dental, while two studies used laboratory scanners by 3shape (D900). Now, the question is whether the writers' choice of the same system was a coincidence or if these software programs are actually that effective and economical to achieve the intended goals. Therefore, more research is required to determine which program produces the best outcomes. One study used 3D printing, whereas the other three milled the crowns [32]. A RAYDENT 3D printer and RAYDENT photopolymer material (RAYDENT C and B; Ray Co., Ltd., Hwaseong-si, Korea) were used to print the crowns. According to earlier research, 5-axis milling machines have a better-fit precision than 4-axis units, especially in axial internal gaps and occlusal marginal gaps. Furthermore, it has been discovered that 5-axis milling is more accurate than rapid prototyping methods. The crowns in this article were made using the core-iTec 550i and Ceramill Motion 2, two popular 5-axis milling machines. According to the review, full coverage restorations produced with CBCT technology and a fully digital workflow have marginal adaptations that are comparable to or better than those produced with intraoral and extraoral scanners [37]. It is noted, meanwhile, that corporate firms and Carestream imaging software companies provided funding for two of the investigations, which might have influenced the findings. Additionally, the presence of metal restorations, which can introduce artifacts into CBCT images and influence reconstruction accuracy, is one of the many oral cavity-related factors that may have an impact on the in vitro research. According to the review, additional high-caliber studies are required to assess crowns' marginal fit using CBCT scans and to improve the body of existing information for greater comprehension and clinical judgment. Clinical evaluation of the final restorations' definitive fit is still pending, despite trials demonstrating encouraging outcomes using CBCT data.

Limitations

This review discovered that the variety in the material type, preparation design, intrinsic CAD process parameters, milling instrument shape, and type, material behavior during milling, and marginal fit assessment method employed in each study limited the evaluation of study quality of the included studies. The data could not be quantitatively analyzed because of the significant degree of variability among the studies. As a result, care should be taken before drawing broad conclusions.

Future scope

In dentistry, CBCT technology makes it possible to gather and create images digitally and in three dimensions. However, because CBCT and CAD/CAM systems have different data formats, it can be difficult to integrate CBCT data with other digital devices, indicating the need for further research in this area.

Conclusion

The following results were reached within the parameters of the systematic review:

- Numerous investigations have demonstrated that a marginal adaption of less than 200 microns is deemed clinically acceptable.
- The marginal fit of the crowns was significantly impacted by the CBCT images' voxel resolution.
- For the manufacture of single crowns, CBCT provides a dependable substitute for traditional scanners; there is no discernible difference in the marginal fit between crowns made using CBCT and conventional scanners.

Therefore, it may be said that there is a significant lack of agreement on the various digital crown fabrication techniques. Additionally, more clinical research employing standardized procedures is required.

Acknowledgments: The authors acknowledge Saveetha University for all the help and support.

Conflict of interest: None

Financial support: None

Ethics statement: None

References

1. Alghazzawi TF. Advancements in CAD/CAM technology: options for practical implementation. J Prosthodont Res. 2016;60(2):72-84.
2. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3-12.
3. Proussaefs P. Custom CAD-CAM healing abutment and impression coping milled from a poly (methyl methacrylate) block and bonded to a titanium insert. J Prosthet Dent. 2016;116(5):657-62.
4. Poticny DJ, Klim J. CAD/CAM in-office technology: innovations after 25 years for predictable, esthetic outcomes. J Am Dent Assoc. 2010;141 Suppl 2:5S-9S.
5. Karaokutan I, Sayin G, Kara O. In vitro study of fracture strength of provisional crown materials. J Adv Prosthodont. 2015;7(1):27-31.
6. Banerjee A, Watson TF. Pickard's guide to minimally invasive operative dentistry. OUP Oxford, 2015.
7. Khng KYK, Ettinger RL, Armstrong SR, Lindquist T, Gratton DG, Qian F. In vitro evaluation of the marginal integrity of CAD/CAM interim crowns. J Prosthet Dent. 2016;115(5):617-23.
8. Mai HN, Lee KB, Lee DH. Fit of interim crowns fabricated using photopolymer-jetting 3D printing. J Prosthet Dent. 2017;118(2):208-15.

9. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health. 2017;17(1):124.
10. Koch GK, Gallucci GO, Lee SJ. Accuracy in the digital workflow: from data acquisition to the digitally milled cast. J Prosthet Dent. 2016;115(6):749-54.
11. Şeker E, Ozcelik TB, Rathi N, Yilmaz B. Evaluation of marginal fit of CAD/CAM restorations fabricated through cone beam computerized tomography and laboratory scanner data. J Prosthet Dent. 2016;115(1):47-51.
12. Corso M, Abanomy A, Di Canzio J, Zurakowski D, Morgano SM. The effect of temperature changes on the dimensional stability of polyvinyl siloxane and polyether impression materials. J Prosthet Dent. 1998;79(6):626-31.
13. Rodriguez JM, Bartlett DW. The dimensional stability of impression materials and its effect on in vitro tooth wear studies. Dent Mater. 2011;27(3):253-8.
14. Nedelcu RG, Persson ASK. Scanning accuracy and precision in 4 intraoral scanners: an in vitro comparison based on 3-dimensional analysis. J Prosthet Dent. 2014;112(6):1461-71.
15. Drago C, del Castillo R, Peterson T. Immediate occlusal loading in edentulous jaws, CT-guided surgery, and fixed provisional prosthesis: a maxillary arch clinical report. J Prosthodont. 2011;20(3):209-17.
16. Coachman C, Calamita MA, Sesma N. Dynamic documentation of the smile and the 2D/3D digital smile design process. Int J Periodontics Restorative Dent. 2017;37(2):183-93.
17. Joda T, Brägger U, Gallucci G. Systematic literature review of digital three-dimensional superimposition techniques to create virtual dental patients. Int J Oral Maxillofac Implants. 2015;30(2):330-7.
18. Park TJ, Lee SH, Lee KS. A method for mandibular dental arch superimposition using 3D cone beam CT and orthodontic 3D digital model. Korean J Orthod 2012;42(4):169-81.
19. Goldman M, Laosonthorn P, White RR. Microleakage—Full crowns and dental pulp. J Endod. 1992;18(10):473-5.
20. Abduo J, Lyons K, Swain M. Fit of zirconia fixed partial denture: a systematic review. J Oral Rehabil. 2010;37(11):866-76.
21. Felton DA, Bayne SC, Kanoy BE, White JT. Effect of air abrasives on marginal configurations of porcelain-fused-to-metal alloys: an SEM analysis. J Prosthet Dent. 1991;65(1):38-43.
22. Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. J Clin Periodontol. 1983;10(6):563-78.
23. Euán R, Figueras-Álvarez O, Cabratosa-Termes J, Oliver-Parra R. Marginal adaptation of zirconium dioxide copings: influence of the CAD/CAM system and the finish line design. J Prosthet Dent. 2014;112(2):155-62.
24. Buduru S, Mesaros A, Culcitchi C, Moldovan M, Prodan D, Szuhanek C. Multivariate assessment of marginal fit of three types of dental crowns using three scanning systems for CAD-CAM technology - in vitro pilot study. Mater Plast. 2018;55(3):376-9.
25. Goiato MC, Santos MR, Pesqueira AA, Moreno A, dos Santos DM, Haddad MF. Prototyping for surgical and prosthetic treatment. J Craniofac Surg. 2011;22(3):914-7.
26. Ganz SD. Cone beam computed tomography–assisted treatment planning concepts. Dent Clin N Am. 2011;55(3):515-36.
27. Rinaldi M, Ganz SD, Mottola A. Partial edentulism, Computer implant surgery. Computer-Guided Applications for Dental Implants, Bone Grafting, and Reconstructive Surgery (Adapted Translation). 2016;157-60.
28. Kauling AE, Keul C, Erdelt K, Kühnisch J, Güth JF. Can lithium disilicate ceramic crowns be fabricated on the basis of CBCT data? Clin Oral Investig. 2019;23:3739-48.
29. Kale E, Cilli M, Özçelik TB, Yilmaz B. Marginal fit of CAD-CAM monolithic zirconia crowns fabricated by using cone beam computed tomography scans. J Prosthet Dent. 2020;123(5):731-7.
30. Russo LL, Caradonna G, Biancardino M, De Lillo A, Troiano G, Guida L. Digital versus conventional workflow for the fabrication of multiunit fixed prostheses: a systematic review and meta-analysis of vertical marginal fit in controlled in vitro studies. J Prosthet Dent. 2019;122(5):435-40.
31. Belgin HB, Kale E, Özçelik TB, Yilmaz B. Marginal fit of 3-unit CAD-CAM zirconia frameworks fabricated using cone beam computed tomography scans: an experimental study. Odontol. 2022;110:339-48.

32. Kim YH, Shin JY, Lee A, Park S, Han SS, Hwang HJ. Automated cortical thickness measurement of the mandibular condyle head on CBCT images using a deep learning method. Sci Rep. 2021;11(1):14852.
33. Kim YH, Jung BY, Han SS, Woo CW. Accuracy evaluation of 3D printed interim prosthesis fabrication using a CBCT scanning-based digital model. PLoS One. 2020;15(10):e0240508.
34. Ponnanna AA, Maiti S, Rai N, Jessy P. Three-dimensional-Printed malo bridge: digital fixed prosthesis for the partially edentulous maxilla. Contemp Clin Dent. 2021;12(4):451-3.
35. Merchant A, Ganapathy DM, Maiti S. Effectiveness of local and topical anesthesia during gingival retraction. Braz Dent Sci. 2022;25(1):2591.
36. Aparna J, Maiti S, Jessy P. Polyether ether ketone - as an alternative biomaterial for Metal Richmond crown-3-dimensional finite element analysis. J Conserv Dent. 2021;24(6):553-7.
37. Maiti S, Rai N, Appanna P, Jessy P. Digital telescopic denture- a viable treatment modality of preventive prosthodontics: clinical report. Ann Dent Spec. 2022;10(4):1-4.