Review Article

EVALUATION OF THE MARGINAL FIT OF CAD/CAM CROWNS USING CBCT AND DIGITAL SCANNERS

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ABSTRACT

With the evolution of CAD/CAM technology, obtaining accurate digital data has become important for the long-term success of prostheses. The present work focuses on systematically identifying and evaluating the literature on the digitization process using CBCT for fabricating CAD/CAM crowns and comparing it to those obtained using routine scanners to assess fit. Using the PRISMA guidelines. The keywords were "In teeth requiring full veneer crowns (P), does the scanning technique (I) provide better accuracy and marginal fit (O) compared with the routine digital methods of fabrication (C). A comprehensive electronic search from 2015 to January 2023 was done. All the studies comparing the fit of prostheses fabricated using CBCT and intra-oral scanners were included. An electronic database search identified 260 articles. 4 studies were included to meet the research question. All 4 studies analyzed the marginal discrepancies of crowns fabricated digitally using CBCT. There was no statistically significant difference observed in the marginal fit of crowns. Limited studies are available comparing the fit of crowns fabricated using CBCT, intraoral scanners, and extraoral scanners. The current systematic review identifies the need for high-quality trials evaluating the accuracy and fit of the crowns/ prostheses fabricated by using CBCT scans as the intra-oral scanners.

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

Introduction

The use of digitalization in the field of dentistry has become common, as they have been found to have many advantages over traditional methods [1-3]. Studies have shown that using these techniques can improve the fit and accuracy of dental prostheses, with some researchers finding that crowns created using 3D printing have better marginal fits than those made using traditional or CAD/CAM milling methods [4-8].

The use of digitally generated models has become a popular method for treatment planning and the materials are now readily available as prefabricated blocks and blanks [9]. One way to generate a such model is by scanning a gypsum cast using a scanner, but the impressions can cause patient discomfort, gag reflex, pain during retraction and may also result in distortion of the impression because of different disinfectant protocols [10, 11]. Another way is through intraoral scanning, but this method is expensive and not always available [12-14]. Additionally, they can also be created from DICOM images which can be converted into standard tessellation language (STL) files. These models can then be used to create patient-specific guides, implant-supported fixed dental prostheses (FDPs), and FDPs without needing conventional impressions [14-16]. Superimposing CBCT image files and STL files has been suggested as a reliable and efficient method, which is also cost and time-efficient with high patient acceptance [16-18].

The marginal fit of full coverage restorations is crucial for clinical success [19, 20]. Misfit of crowns can negatively impact the teeth and surrounding soft tissue [19, 21, 22]. Currently, the acceptable marginal fit is not defined, but some researchers suggest that the gap should not exceed 100mm for CAD-CAM restorations [23, 24]. Clinicians have access to new diagnostic tools and approach to prosthetic surgical planning and fabrication thanks to the advent of technologies such as CT and MRI. One of these technologies is cone beam CT (CBCT), which enables 3D high-resolution imaging using low doses of radiation for diagnostic treatment planning. Digital data can also be used to reconstruct 3D images and create patient-specific abutments from a standard tessellation language (STL) file exported from interactive software, without the need for intraoral impressions or stone casts. However, currently, no published study compares the marginal discrepancy of crowns created using data from digital scanning versus data obtained from CBCT [25-27]. The purpose of this systematic review is to determine whether the use of CBCT scan for fabrication of full coverage restorations can yield better marginal fit when compared to routinely used digital methods. The null hypothesis is that digital and CBCT scanning methods of fabrication result in restorations with similar marginal and internal discrepancies.

Materials and Methods

This review was done following PRISMA guidelines (Moher, 2010). 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

Advanced search of the Pubmed search engine was used using the following keywords:

(((((((((((Occlusal discrepancies) OR (occlusal disharmony)) OR (esthetic outcomes)) OR (occlusal fit)) OR (occlusal misfit)) OR (Marginal fit)) OR (Marginal adaptation)) OR (t scan)) OR (pink esthetic score)) OR (patient satisfaction)) OR (quality of life)) OR (periodontal index)) OR (gingival index)

AND (((((((((Cbct) OR (Cone beam computed tomography)) OR (c arm ct)) OR (cone beam ct)) OR (digital volume tomography)) OR (field of view)) OR (voxel)) OR (DICOM)) OR (carestream)) OR (imaging software)) OR (intraoral scanner)

AND (((((((((((((((Acrylic temporary crowns) OR (temporization)) OR (provisional restoration)) OR (pmma)) OR (polymethylmethacrylate)) OR (crown fabrication)) OR (cad cam)) OR (additive manufacturing)) OR (subtractive manufacturing)) OR (3d printing)) OR (3d printed crowns)) OR (milling)) OR (digitalization)) OR (direct digitalization)) OR (indirect digitalization)) OR (computer aided design)) OR (computer aided manufacturing)

AND (((((((((Patients undergoing full mouth rehabilitation) OR (full mouth rehabilitation)) OR (fmr)) OR (reduced vertical dimension)) OR (reduced vertical height)) OR (decreased vertical dimension)) OR (fixed prostheses)) OR (fixed prosthesis)) OR (fixed dental prostheses)) OR (crowns)) OR (fixed partial dentures)

An advanced search of the Cochrane search engine was done and the search yielded 9 studies. Science direct search engine was searched using the following keywords with an advanced search engine:

(CBCT OR Cone beam computed tomography) AND (intraoral scanners OR extraoral scanner) AND (fixed prosthesis OR crowns)

The search yielded 58 studies. Europe PMC database search was carried out and it yielded 1 result. The Lilac database was searched and no relevant studies were obtained. Google Scholar database yielded 62 studies.

Two reviewers, A.S. and S.M., conducted an independent and standardized assessment of eligible studies. The process was unblinded. In the first round, they screened the titles and abstracts of publications resulting from the database search. In the second round, they read the full text of all articles that were considered eligible from the first round. Only studies that met valid criteria were included in the systematic review and considered for data extraction.

Inclusion 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
- Studies published in English only.

Exclusion criteria: **(Table 1)**

- Use of a combination of either technique for data acquisition for the fabrication of prostheses.
- Animal studies
- Literature reviews
- Articles in any other language other than English
- Ongoing studies in which results have not yet been published.

Table 1. Characteristics of excluded studies

S/No	Study	Reason for exclusion
1.	Xiaoqiang Liu *et al*., 2017	Both CBCT and intra-oral scans were merged. No comparison between the two.
2.	Nicholas B DuVall. *et al*., 2020	CBCT took after the fabrication of the prosthesis for implant treatment planning.
3.	Salem *et al*., 2016	fit accuracy of 3 different CAD/CAM crowns assessed using CBCT, did not use CBCT for fabrication.
4.	Hafez A. *et al*., 2019.	Internal fit of 2 CAD/CAM systems evaluated using CBCT.
5.	Moaty et al, 2018	fracture resistance and fit evaluated using CBCT; the abstract did not match the search result.
6.	Akmal *et al*., 2020	marginal gap evaluated using CBCT.
7.	ZP Evans *et al*., 2018	CBCT and CAD/CAM, are both used for the fabrication and customization of root-analog dental implants.

8.	Sergio Lins de-Azevedo-Vaz *et al.*, 2020	CBCT is used for evaluation of misfit of implant abutment joint (IAJ) and not for prosthesis fabrication.
9.	Omer Ali Decani *et al.*, 2018	CBCT was used to evaluate the internal fit of different groups included, not for fabrication of prosthesis.
10.	Renaud Noharet *et al.*, 2019	Combination of CBCT and CAD/CAM is used for preserving the emergence profile after immediate extraction and aid in implant placement, not used for interim crown fabrication.
11.	Giorgio Polara *et al.*, 2020	CBCT scan was used for the fabrication of interim screw-retained crowns, however, assessment of crown adaptation time (chair time spent) was evaluated in comparison to crowns fabricated using 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
- Country where the studies were done
- Sample size
- Study groups: intervention and control
- Outcome assessment: variables assessed and method of evaluation

The variables observed are mentioned in **Tables 2 and 3**. The mean values and statistical significance of the variables observed in the study were thoroughly examined.

The studies were divided into two groups based on the fabrication method: the CBCT group and the digital group. The primary outcomes measured were the differences in the marginal between the groups. Qualitative analyses were conducted separately for the in-vitro studies based on the SMD. For the analysis of marginal fit, the mean difference (MD) and its standard error were computed. The Kolmogorov-Smirnov and Shapiro-Wilks tests were used to determine if the data were normally distributed [28]. However, one study did not achieve normal distribution within-group data and homoscedasticity [29]. The remaining two studies failed to give an account of the homogeneity of data. Unpaired tests were carried out because of the small sample size; this may have also influenced the results obtained.

An assessment of the risk of bias for the included studies was not conducted because no suitable tool is currently available for in-vitro studies [30].

Results and Discussion

A systematic search of electronic databases, including PubMed (130 studies), Cochrane library (9 studies), Google Scholar (62 studies), and ScienceDirect (58 studies), was conducted. No studies were found in the LILACS and WILEY online library databases, and one study was obtained from EuropePMC. After removing duplicates and reviewing the titles, 24 studies were identified. Of these, 9 studies were excluded from the systematic review. The full-text articles for the remaining 15 studies were obtained, and their bibliographies were also reviewed to include any additional studies. Ultimately, a total of 4 studies met the inclusion and exclusion criteria of the intended research **(Figure 1)**.

Characteristics of the included studies were discussed and the outcome was assessed using standard mean values of marginal fit of crowns **(Tables 2 and 3)**. Ediz Kale *et al.* [31] compared 3 groups namely: crowns fabricated using CBCT scans, crowns fabricated using CBCT and laboratory scanners, and crowns fabricated using laboratory scanners only (control group). The vertical marginal discrepancy was evaluated using a zoom microscope. They observed that a better marginal fit was obtained when only CBCT or laboratory scanners were used rather than a combination of both. However, a statistical difference was seen between the CBCT group and the Laboratory scanner group ($p<0.001$).

In another study done by Young Hyun Kim *et al.* [32, 33], 2 groups were compared: crowns fabricated using CBCT and crowns fabricated using intraoral scanners. the marginal gap was evaluated using the replica technique using light body PVS materials and marginal gaps were evaluated using a digital microscope. Measured errors were within the clinically permitted range (177-400 microns) and they observed that higher resolution CBCT could give better results, thereby aiding in the digital model acquisition and prosthesis fabrication.

Emre Seker *et al.* [11], compared the marginal fit of crowns fabricated using extraoral laser scanners and different resolutions of voxel (0.3, 0.2, and 0.125) images. The vertical marginal discrepancy was observed at 4 sites of the crowns using a zoom stereo microscope. they observed better results with extraoral laser scanners; however, CBCt scans with 0.125 voxel images gave better results. Kauling *et al.* [11, 28] compared 2 CBCT systems with intraoral (IOS) and extraoral (EOS) scanners and checked for the accuracy and fit of the crowns fabricated using 3D analysis. marginal fit of CBCT1, CBCT2, IOS, and EOS showed significant differences. The marginal fit of CBCT1 AND CBCT2 was within the range of clinical acceptance, however not as good as the scanners.

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
Ediz 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
Young Hyun 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.
Emre Seker *et al.*, 2015	ex-Vivo study	university setting	Turkey	4 groups N=9 per group	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:N=9 Control group, crown fabricated using an extra-oral laser scanner(D900 3Shape)	i)vertical marginal discrepancy using a zoom stereo microscope.	i) vertical marginal discrepancy checked at 4 sites per crown.
Ana Elisa Colle Kauling *et al.* 2019	in-vitro study	university setting	Germany	4 groups N=12 in each group	group 1: CBCT1 (CS9300) Group 2: CBCT 2(CS8100) Group 3: extraoral scanner (Ceramill Map 400)	group 4: Intra-oral scanner (CS3600)	i)Accuracy of the dataset ii)Analysis of fit	i)accuracy of dataset quality using Geomagic superimposition software ii)fit evaluated using the replica technique.

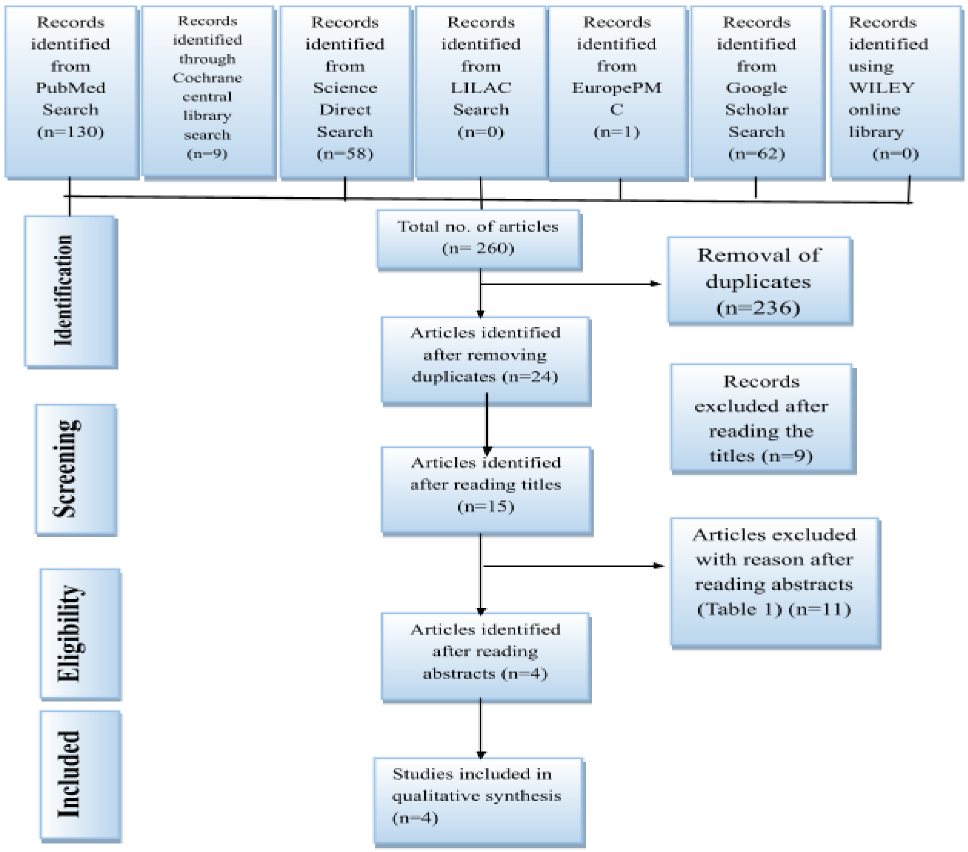

Figure 1. PRISMA Flowchart for article selection

Table 3. General information on the results of included studies

S/No	Author and year	Method of fabrication of prosthesis	Results obtained	Overall conclusion
1	**Ediz Kale *et al.*, 2018** [29]	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 group (p=0.274).	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	**Young Hyun Kim *et al.*, 2020.** [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.	Root mean square value of CBCT and IOS ranged from 41um- 126um (mean=60.2um) Marginal gap: mean=132.96um Internal gap: mean=255.88um	Measured errors were within the clinically permitted range (177-400um). High-resolution CBCT could be widely used for digital model acquisition and prosthesis fabrication.

3	**Emre Seker *et al.*, 2015** [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 resolution	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	**Ana Elisa Colle Kauling *et al.*, 2019** [11, 28]	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.

Previous studies and reviews have yielded conflicting findings concerning the marginal and internal adaptation of full coverage restorations fabricated using different methods, which prompted the need for an updated review. The main objective of this review is to evaluate the marginal fit of crowns fabricated using CBCT scans in comparison to digital intraoral and extraoral scanners. Data acquisition can be done through direct digitization using an IOS or indirect digitalization using an EOS or a CBCT image. Indirect digitalization requires a conventional impression with elastomeric materials to produce a gypsum cast, which may cause several fabrication errors. The studies reviewed were all conducted in Eastern countries and there is a lack of evidence in the Western world, which may limit the external validity of the review.

Marginal fit

There is currently no agreement on what constitutes an acceptable level of marginal discrepancy in dental restorations. Some authors have proposed a threshold of 120 micrometers or lower [28], while others have suggested that a gap of 200 micrometers or less is appropriate [11, 28, 33]. Most of the studies reviewed reported marginal gap values within this range. To evaluate the marginal fit, 2D analysis was performed in all the included studies, either using a zoom stereo microscope or a digital microscope, but this method only allows for a limited number of measuring points and sections, which may not provide a comprehensive representation of the crown's overall fit. In addition, some studies, such as those by Emre Seker *et al*. and Ediz Kale, used a zoom stereo microscope and real-time measurement software and were conducted by a single operator, which could have introduced bias in the results. Alternative methods, such as 3D analysis using micro-computed tomography or the triple-scan protocol, could provide more accurate and reliable results by enabling multiple-point measurements. Therefore, the included studies in this review may be considered to have low validity and reliability.

Cone beam computed tomography

The research examined the use of various types of CBCT scanners, including i-CAT, RAYSCAN, and Carestream dental imaging. One study found that the size of the voxel used in the scan had a significant impact on the marginal integrity of CAD CAM fabricated crowns when applied to virtual 3D tooth models generated from CBCT scans. Another study evaluated the accuracy of two generations of CBCT scanners and found that the second generation provided better accuracy than the first generation [34-36]. Practitioners should be aware of the scanning parameters to provide optimized results while balancing the risks of radiation exposure. Further research is necessary to investigate the influence of all coexisting parameters on the reconstruction accuracy of virtual casts.

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 arises whether these softwares are really that efficient and cost-effective to obtain the desired results, or was it just a coincidence that the authors chose to use the same system. Hence, more research needs to be done in terms of which software gives better results. 3 studies fabricated the crowns by milling whereas 1 used 3d printing [32]. The crowns were printed using RAYDENT 3d printer and RAYDENT photopolymer material (RAYDENT C & B; Ray Co., Ltd., Hwaseong-si, Korea). Previous studies have found that 5-axis milling units present a higher accuracy of fit than 4-axis units, particularly in occlusal marginal gaps and axial internal gaps. Additionally, 5-axis milling has been found to be more accurate than rapid prototyping techniques. In this review, two commonly used 5-axis milling machines, the core-iTec 550i and Ceramill Motion 2 machines were used to fabricate the crowns.

The review suggests that using a fully digital workflow with CBCT technology leads to the production of full coverage restorations with similar or improved marginal adaptation compared to those made using intraoral and extraoral scanners [37]. However, it is mentioned that two of the studies were funded by corporate companies and Carestream imaging software companies, which may have introduced bias in the results. Furthermore, the in vitro studies may be affected by various oral cavity-related factors, such as the presence of metal restorations, which can create artifacts in CBCT images and impact the accuracy of reconstruction. The review suggests that more high-quality research is needed to evaluate the marginal fit of crowns using CBCT scans and to enhance current literature for better understanding and clinical judgment. While studies have shown promising results with CBCT data, the definitive fit of final restorations is yet to be evaluated clinically.

Limitations

This review found that the assessment of study quality of the included studies was limited due to the diversity in the type of material, preparation design, intrinsic parameters for the CAD process, shape and type of milling instruments, the behavior of the material during milling and method of assessing marginal fit used in each study. The high level of heterogeneity among the studies prevented the quantitative analysis of the data. Therefore, any general conclusions should be made with caution.

Future scope

CBCT technology in dentistry enables a digital and 3D method of obtaining and creating images, but integrating CBCT data with other digital devices is challenging because of incompatible data formats between CBCT and CAD/CAM systems, showing the need for more research in this field.

Conclusion

Within the limits of the systematic review, the following conclusions were drawn:

- Many studies have shown that a marginal adaptation of fewer than 200 microns is considered clinically acceptable.
- The voxel resolution of CBCT images highly influenced the marginal fit of the crowns.
- No significant difference in the marginal fit exists between crowns fabricated using CBCT and conventional scanners.
- CBCT offers a reliable alternative to conventional scanners for the fabrication of single crowns.

Thus, it can be concluded that there is a substantial lack of consensus relating to different methods of digital fabrication of crowns. Further, more clinical studies need to be done using standardized protocols.

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