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SYSTEMATIC REVIEW

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

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ABSTRACT

Statement of problem. Limited evidence is available for the marginal fit of multiunit fixed dental prostheses (MFDPs) fabricated with digital technologies compared with those fabricated with conventional techniques.

Purpose. The purpose of this systematic review and meta-analysis was to answer the following question: Does digital workflow for the fabrication of tooth-supported or implant-supported MFDPs provide better marginal fit than the conventional workflow?

Material and methods. PubMed, SCOPUS, EBSCO, and Web of Science databases were searched for controlled in vitro studies addressing direct comparison of the fit of MFDPs produced with digital or conventional workflows and excluding studies addressing interim restorations, MFDPs on mixed abutments (teeth and implants), or studies in which reproduction of the basic master cast was performed in 1 group. Vertical and horizontal marginal fit were the primary outcomes; meta-analysis was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, with subgroup analysis for tooth- or implant-supported MFDPs.

Results. Four studies published between 2011 and 2015 met the inclusion criteria and were included in the review. They investigated 3-unit partial fixed dental prostheses, exhibited a high degree of heterogeneity, and reported data only regarding vertical marginal fit. MFDPs fabricated with digital techniques presented a nominally higher vertical marginal discrepancy than those fabricated with the conventional technique, but the mean difference (MD) (19.8 μm, 95% confidence interval [CI]: −12.1; 51.7) has no statistical significance. The same is also applicable to subgroup analysis for a tooth-supported (MD=45.8 μm, 95% CI: −45.4; 137.0) or implant-supported (MD=14.7 μm, 95% CI: −38.6; 68.1) MFDP.

Conclusions. Digital technologies offer a reliable alternative to conventional techniques for the fabrication of tooth- or implant-supported 3-unit fixed partial dentures; additional studies with up-to-date technologies and for prostheses with more than 3 units are recommended to provide stronger evidence. (J Prosthet Dent 2019;122:435-40)

Conventional techniques for producing multiple-unit fixed dental prostheses (MFDPs) are currently, routinely, and successfully used.[1] However, they require a high degree of standardization of the workflow to avoid errors that may impair the accuracy of the definitive result. Critical steps are impression making and processing, cast production and storage, and adequate material handling during the production stage. Errors may be introduced by inadequate impression tray selection and preparation, limitations in the impression material flow and hydrophilicity, occurrence of tearing and deformation of the impression during removal,[2] or improper procedures and timing for impression handling and pouring.[3] Errors may also occur during cast

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Clinical Implications

Computer-aided design and computer-aided manufacturing (CAD-CAM) technologies offer a reliable alternative to conventional techniques for the fabrication of tooth- or implant-supported 3-unit fixed partial dentures.

production and can be related to the dimensional stability of the impression material, variation in temperature, surface wettability of the gypsum product and disinfection procedures,[4] or accidental formation of air bubbles. Material selection and adequate procedures are also mandatory in the production phase to control for thermal expansion and contraction, leading to potential framework distortion.[5] One or more of these variables can occur and affect the accuracy of the prosthesis.

In recent years, the development of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies has led to the widespread use of the digital workflow for dental prosthesis fabrication because it involves fewer clinical appointments, the use of quality-controlled materials, preclinical optimization of the MFDP shape,[6] a higher degree of standardization, and elimination of the drawbacks of conventional techniques, at least in the production phase. If the digital workflow starts with digitization of casts obtained from conventional impressions, only potential errors in the production stage can benefit from CAD-CAM application. Their effectiveness has been addressed in previous studies[7] by analyzing the fit of prostheses produced by digital technologies. However, these investigations typically assessed the accuracy of single crowns,[8] often in an uncontrolled study design,[7] or in some controlled studies, additional reproduction of the definitive cast was performed in 1 group (conventional[9] or digital[10]), which may have introduced bias. Thus, limited evidence is available for the marginal fit of MFDPs fabricated by digital technologies compared with those fabricated by the conventional technique.

The purpose of this systematic review and meta-analysis was to assess the marginal fit of tooth- or implant-supported MFDPs from controlled in vitro studies that directly compared digital and conventional fabrication techniques starting from the same cast.

MATERIAL AND METHODS

The protocol of this systematic review was developed according to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines[11] and the Cochrane Handbook.[12] The review was conducted to answer the following question: Does the digital workflow for the fabrication of tooth-supported or implant-supported MFDPs provide better marginal fit than the conventional workflow?

Only controlled studies directly comparing vertical or horizontal marginal fit between MFDPs fabricated with digital workflow or conventional techniques on natural teeth or implants were considered eligible for inclusion in this review. The following criteria were used for exclusion: interim restorations, reproduction of the definitive cast, or MFDPs on mixed abutments (both teeth and implants).

Direct online research was performed on the following databases: PubMed, SCOPUS, EBSCO, and Web of Science. A partial research of the non−peer-reviewed literature was also performed on Open Grey and Google Scholar. The literature search was carried out by 2 reviewers (M.B., G.C.) in an independent manner. The protocol for the bibliographic research was made up of Medical Subject Heading terms and free-text words combined through Boolean Operators (AND or OR). The following Medical Subject Heading terms were used: "Adaptation," "Dental Marginal," "Dental Internal," and "Fixed Bridge." The following free-text words were used: "conventional," "digital," and "multiple unit prosthesis." In addition, a direct search was performed on the bibliographies of all reviewed articles and on the websites of the following journals: *International Journal of Prosthodontics; Journal of Prosthetic Dentistry; International Journal of Oral and Maxillofacial Implants; Quintessence International; Brazilian Oral Research; Journal of Oral Implantology; Journal of Prosthodontics; Dental Materials; Journal of Dentistry; Odontology; Journal of Oral Rehabilitation; Clinical Oral Implants Research; Clinical Oral Investigations;* and *International Journal of Periodontics and Restorative Dentistry.* In addition, bibliographies of systematic reviews and included articles were manually reviewed to find other articles eligible for the meta-analysis.

In this review, in assessing the marginal fit from the reviewed studies, the margin terminology proposed by Holmes et al[13] was used. Specifically, vertical marginal fit, also known as marginal gap, is defined as the perpendicular measurement from the internal surface of the crown to the margin of the die; a horizontal marginal fit is defined as the marginal misfit measured perpendicular to the path of placement of the casting.

Two reviewers (M.B., G.C.) independently performed the eligibility assessment in an unblinded standardized manner. In the first round, the title and abstract of publications resulting from the database search were screened. Eligible studies were included in the second round, in which the full text of all articles was read. At the end of the second round, only studies fulfilling all the inclusion and exclusion criteria were included in the systematic review and considered for data extraction. Cases of disagreement between reviewers were solved by discussion in a joint session; a third (G.T.) author calculated the value of k-statistic to show the value of agreement between reviewers.[14] The data were tabulated with an ad hoc extraction sheet. For each study, the following data were extracted: name of first author, year of publication, study design, sample size, marginal fit data, number of units, location and type of abutments, prosthesis core material, impression and fabrication technique, implant manufacturer, and examination methods.

For the analysis of marginal fit, the mean difference (MD) and its standard error were calculated. Data were pooled with a fixed or a random effect model with a 50% cutoff value from the Higgins Index. The overall effects were pooled using the inverse of variance test.

All the analyses were performed using a software program (Review Manager v5.2.8; Cochrane Collaboration, 2014) (α=.05). The analysis of the risk of bias of included studies was not performed because an appropriate tool is not available for in vitro studies.

RESULTS

A total of 184 studies were retrieved and screened by title and abstract. After the first screening, 12 articles were considered eligible and read in full. Four of these manuscripts[15-18] were included in the quantitative meta-analysis. All of them investigated more than 2 groups with different production methodologies, and only data for conventional and digital groups were extracted and analyzed. The remaining 8 eligible articles were not included in the meta-analysis because a reproduction of the definitive cast was performed for the conventional[9] or digital[10,19-23] workflow or because the conventional and digital groups did not use the same cast (in the digital group the cast was obtained by digitalization of a conventional impression).[24] The flow chart of the selection process is shown in Figure 1. The value of k-agreement between reviewers was 0.8 and thus was rated as excellent.

The included studies (Table 1) were published between 2011 and 2015. They had a case-control design and analyzed a total of 76 cases (38 in the conventional groups and 38 in the digital groups). All studies evaluated 3-unit fixed partial prostheses: 2 studies investigated implant-supported MFDPs, and the remaining 2 studies focused on tooth-supported MFDPs. All the 4 included studies analyzed vertical marginal fit, and none addressed horizontal marginal fit. The vertical marginal fit was measured using an optical[16-18] or a stereo microscope.[15]

A pooled analysis (Fig. 2) revealed the absence of statistically significant differences (P=.22) for the vertical marginal fit between the digital and conventional protocols (MD=19.8 μm, 95% confidence interval [CI]: −12.1; 51.7). Such results were characterized by a high rate of heterogeneity among the included studies (I^2=82%). Subgroup analysis revealed no statistically significant difference for studies performed on tooth-supported (MD=45.8 μm, 95% CI: −45.4; 137.0) or implant-supported (MD=14.7 μm, 95% CI: −38.6; 68.1) prostheses.

DISCUSSION

The findings of this systematic review and meta-analysis indicated no statistically significant differences in the vertical marginal fit of tooth-supported or implant-supported MFDPs fabricated using digital or conventional techniques. The most popular approach for MFDP production is the conventional method with the lost-wax technique. However, despite its simplicity, it involves several steps and materials that may introduce inaccuracies. Marginal discrepancies can be considered an indicator of accuracy of the restoration and of its production process. Discrepancies of less than 80 μm have been reported to be difficult to detect clinically.[25] A marginal gap between 100 and 150 μm has been considered clinically acceptable.[25-29]

The introduction of CAD-CAM technologies may have improved the predictability of fit and the accuracy of fixed partial prostheses.[30] However, limited evidence is available for the marginal fit of MFDPs fabricated by digital technologies compared with those fabricated by the conventional technique. Marginal discrepancy may result from several procedure-, material-, or operator-dependent variables in one or more steps during impression making and processing, cast production, and storage, as well as material selection and handling in the production phase. Because of the criteria for study selection in the current review, only benefits that may derive from applying CAD-CAM technologies to the MFDP production phase were evaluated; in the included studies, both the digital and conventional protocols started with the digitization of the same cast obtained from a conventional impression. The retrieved studies provided limited data regarding internal or horizontal marginal fit. Therefore, the results of this meta-analysis of controlled in vitro studies addressed only the vertical marginal fit. Such findings revealed that MFDPs fabricated by digital techniques had a higher vertical marginal discrepancy than those fabricated by the conventional technique, but the MD (19.8 μm) was not statistically significant. The subgroup analysis for tooth-supported or implant-supported MFDPs also did not reveal a statistically significant difference. However, the MD of implant-supported MFDPs (14.7 μm) was about one-third of that of tooth-supported MFDPs (45.8 μm).

A direct subgroup comparison of the vertical marginal fit between different digital scanning systems or core materials was not performed because of the limited data

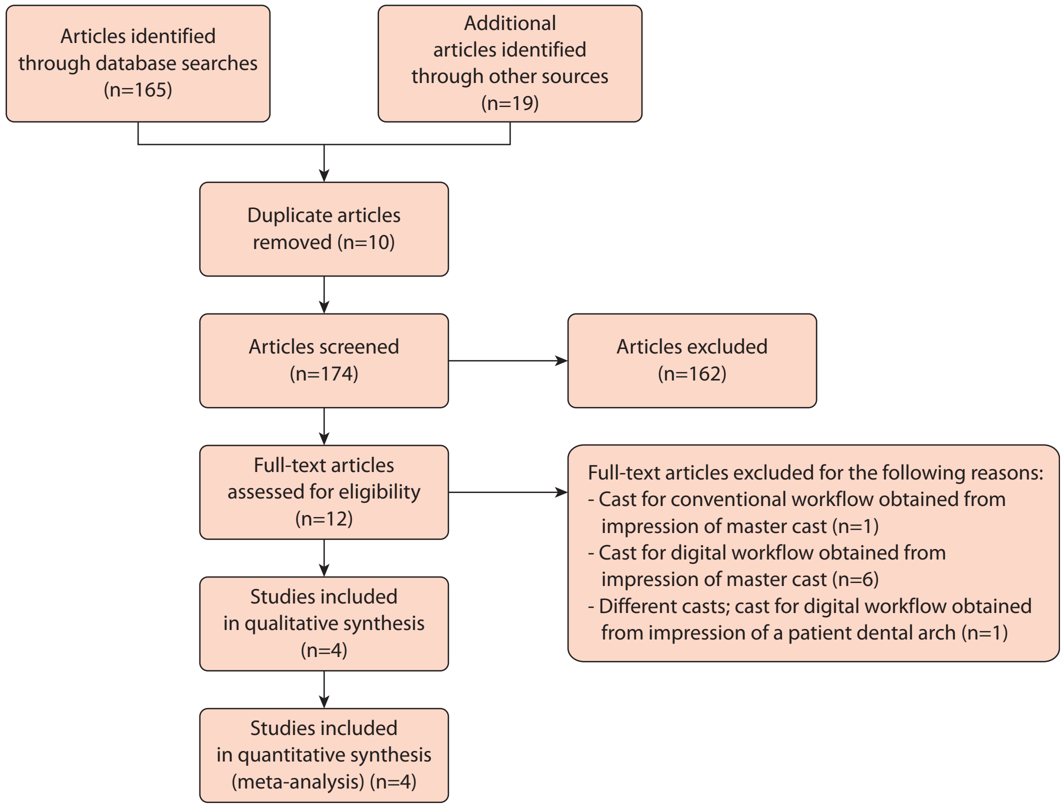

Figure 1. Flow chart of selection process and reasons for exclusion of articles read in full text.

Table 1. Data extracted from studies included in meta-analysis

Study	**Ortorp et al**		**Berejuk et al**		**Varol et al**		**Bayramoglu et al**	
Year	**2011**		**2014**		**2015**		**2015**	
	Conventional	**Digital**	**Conventional**	**Digital**	**Conventional**	**Digital**	**Conventional**	**Digital**
Study design	Case-control study	Case-control study	Case-control study	Case-control study	Case-control study	Case-control study	Case-control study	Case-control study
Number of specimens	8	8	10	10	10	10	10	10
Type of support (tooth, implant)	Tooth	Tooth	Implant	Implant	Tooth	Tooth	Implant	Implant
Number of units	3	3	3	3	3	3	3	3
Region	Premolar and molar	Premolar and molar	Premolar and molar	Premolar and molar	Premolar and molar	Premolar and molar	Premolar and molar	Premolar and molar
Type of impression/scanner	Silicone	3Shape D640	Silicone	3Shape D700	Silicone	Not reported	Polyvinyl siloxane	Sirona Cerec Blue-cam
Core material	Co-Cr	Co-Cr	Co-Cr	Co-Cr	Ni-Cr	Zirconia	Ni-Cr	Zirconia
Fabrication technique/ CAD-CAM system	Lost-wax	Not reported	Lost-wax	Not reported	Lost-wax	Cerec inLab; Cerec MC XL	Lost-wax	Cerec inLab; Cerec MC XL
Examination method	Stereo microscope	Stereo microscope	Light microscope	Light microscope	Light microscope	Light microscope	Light microscope	Light microscope
Vertical marginal fit ±SD (µm)	118 ±49.7	222.5 ±124.6	11.56 ±8.74	1.85 ±1.50	77.26 ±29.23	86.17 ±27.61	75.4 ±16.6	120.4 ±54.5

CAD-CAM, computer-aided design and computer-aided manufacture; Co-Cr, cobalt-chromium; Ni-Cr, nickel-chromium; SD, standard deviation.

available. Considering the discrepancies reported, they probably do not affect the clinical acceptability of tooth-supported or implant-supported MFDPs or the fabrication method.

The findings of this systematic review should be interpreted with caution because it was based on a small number of in vitro studies exhibiting a high degree of heterogeneity. In addition, the results are applicable only to 3-unit tooth-supported or implant-supported partial fixed dental prostheses. However, the studies included in the current meta-analysis were published 3 to 7 years ago, and the oldest study[15] showed the greatest

Study or Subgroup	Digital Mean	Digital SD	Digital Total	Conventional Mean	Conventional SD	Conventional Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 Tooth-supported								
Ortorp et al. 2011	222.5	124.6	8	118	49.7	8	8.9%	104.50 (11.54, 197.46)
Varol et al. 2014	86.17	27.61	10	77.26	29.23	10	29.8%	8.91 (−16.01, 33.83)
Subtotal (95% CI)			**18**			**18**	**38.7%**	**45.78 (−45.41, 136.98)**
Heterogeneity: τ^2=3363.19; χ^2=3.79, df=1 (*P*=.05); I^2=74%								
Test for overall effect: Z=0.98 (*P*=.33)								
1.1.2 Implant-supported								
Bayramoglu et al. 2015	120.4	54.5	10	75.4	16.6	10	25.2%	45.00 (9.69, 80.31)
Berejuk et al. 2014	1.85	1.5	10	11.56	8.74	10	36.1%	−9.71 (−15.21, −4.21)
Subtotal (95% CI)			**20**			**20**	**61.3%**	**14.75 (−38.56, 68.06)**
Heterogeneity: τ^2=1330.37; χ^2=9.00, df=1 (*P*=.003); I^2=89%								
Test for overall effect: Z=0.54 (*P*=.59)								
Total (95% CI)			**38**			**38**	**100.0%**	**19.79 (−12.10, 51.69)**
Heterogeneity: τ^2=726.10; χ^2=16.35, df=3 (*P*=.001); I^2=82%								
Test for overall effect: Z=1.22 (*P*=.22)								
Test for subgroup differences: χ^2=0.33, df=1 (*P*=.56). I^2=0%								

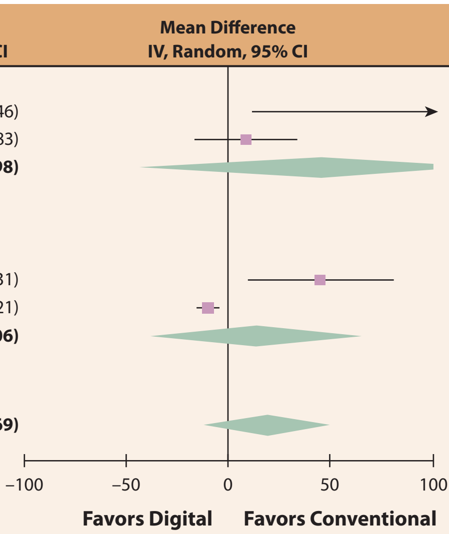

Figure 2. Forest plot evaluating mean difference (μm) with random effects model for investigated outcome (vertical marginal fit). Subgroup analysis for tooth- and implant-supported prostheses also presented. CI, confidence interval; SD, standard deviation; IV, inverse variance.

difference between digital and conventional techniques. Digital technologies have evolved tremendously in the past 7 years.

CONCLUSIONS

Based on the results of this systematic review with meta-analysis, the following conclusions were drawn:

1. CAD-CAM technologies offer a reliable alternative to conventional techniques for the fabrication of tooth- or implant-supported 3-unit partial fixed dental prostheses.
2. Additional studies with up-to-date technologies and investigating partial fixed dental prostheses with more than 3 units are needed to provide stronger evidence.

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Noteworthy Abstracts of the Current Literature

Comparison of three-dimensional accuracy of digital and conventional implant impressions: Effect of inter-implant distance in an edentulous arch

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Purpose. This study compared the three-dimensional (3D) accuracy of conventional impressions with digital impression systems (intraoral scanners and dental laboratory scanners) for two different inter-implant distances in maxillary edentulous arches.

Material and methods. Six impression systems comprising one conventional impression material(Impregum), two intraoral scanners (TRIOS and True Definition), and three dental laboratory scanners (Ceramill Map400, inEos X5, and D900) were evaluated on two completely edentulous maxillary arch master models (A and B) with six and eight implants, respectively. Centroid positions at the implant platform level were derived using either physical or virtual probe hits with a coordinate measuring machine. Comparison of centroid positions between master and test models (n=5) defined linear distortions (d_x, d_y, d_z), global linear distortions (d_R), and 3D reference distance distortions between implants (ΔR). The two-dimensional (2D) angles between the central axis of each implant to the x- or y-axes were compared to derive absolute angular distortions ($Absd\theta_x$, $Absd\theta_y$).

Results. Model A mean d_R ranged from 8.7 ±8.3 μm to 731.7 ±62.3 μm. Model B mean d_R ranged from 16.3 ±9 μm to 620.2 ±63.2 μm. Model A mean $Absd\theta_x$ ranged from 0.021 ±0.205 degrees to -2.349 ±0.166 degrees, and mean $Absd\theta_y$ ranged from -0.002 ±0.160 degrees to -0.932 ±0.290 degrees. Model B mean $Absd\theta_x$ ranged from -0.007 ±0.076 degrees to -0.688 ±0.574 degrees, and mean $Absd\theta_y$ ranged from -0.018 ±0.048 degrees to -1.052 ±0.297 degrees. One-way analysis of variance (ANOVA) by Impression system revealed significant differences among test groups for d_R and ΔR in both models, with True Definition exhibiting the poorest accuracy. Independent samples t tests for d_R, between homologous implant location pairs in Model A versus B, revealed the presence of two to four significant pairings (out of seven possible) for the intraoral scanner systems, in which instances d_R was larger in Model A by 110 to 150 μm.

Conclusions. Reducing inter-implant distance may decrease global linear distortions (d_R) for intraoral scanner systems, but had no effect on Impregum and the dental laboratory scanner systems. Impregum consistently exhibited the best or second-best accuracy at all implant locations, while True Definition exhibited the poorest accuracy for all linear distortions in both Models A and B. Impression systems could not be consistently ranked for absolute angular distortions.