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SYSTEMATIC REVIEW

# Time efficiency and cost analysis between digital and conventional workflows for the fabrication of fixed dental prostheses: A systematic review

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## ABSTRACT

**Statement of problem.** Time and cost are factors that influence a patient's decision on dental prosthetic treatment. Evidence is needed to demonstrate that restoration using digital systems is more rapid and less costly than the conventional process.

**Purpose.** The purpose of this systematic review was to analyze and compare the duration and cost of fixed dental prostheses fabricated using digital and conventional methods from scanning or impression making to delivery of the prosthesis.

**Material and methods.** A systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P 2015) guidelines. The analysis methods and inclusion criteria were documented in a protocol registered in the Prospective International Register of Systematic Reviews (PROSPERO) (CRD42023458734). The bibliographic search was carried out using PubMed, Cochrane, and PROSPERO databases. The main keywords used were (Prosthodontic OR restorative dentistry OR denture) AND (CAD CAM OR Digital workflow OR Computer Dentistry OR Digital Design) AND (Economic OR cost OR Financial OR time efficiency). Two investigators undertook the different steps of article selection.

**Results.** A total of 8 articles published between 2010 and 2023 were found for the qualitative synthesis by using the search criteria. Two studies showed that conventional impressions took more time than digital scans for the fabrication of a single crown, and 1 study showed the opposite. One study found that a digital scan was faster than conventional impression making for the fabrication of a 3-unit fixed partial denture, and another study showed the opposite. The dental laboratory technician spent more time on the conventional workflow than the digital workflow for the 3-unit framework and veneering process. No difference was found between conventional and digital workflows for clinical evaluation and chairside adjustment for the fabrication of a single crown. No articles have compared the cost of fixed prostheses.

**Conclusions.** The digital pathway can shorten the laboratory process. However, the duration of the impression or scan may vary depending on the technique used. Studies are needed to analyze the cost-effectiveness of the fabrication of tooth-supported restorations. (J Prosthet Dent 2025;133:71-84)

Conventional protocols for the fabrication of crowns and fixed partial dentures have been considered the criterion standard in clinical practice for many decades. Once the tooth has been prepared, a physical impression with impression materials is made and sent to the dental laboratory technician. The fabrication process uses a series of conventional lost-wax and casting processes to create the definitive crown, which is luted to the prepared tooth.[1]

Digital dental technology, including digital scanning, computer-aided design, and computer-aided manufacturing (CAD-CAM), has evolved rapidly.[2] A digital scan is performed using intraoral scanners to create a digital cast, and a CAD software program is used to virtually design the crown. CAM technology is used to

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## Clinical Implications

Time and cost are factors that influence a patient's decision on prosthetic dentistry treatments. The digital pathway reduces both laboratory time and the technical production process. However, the duration of the clinical procedure may vary according to the specific digital or conventional technique used.

fabricate the crown by milling or 3D printing. The crown is refined, polished, and glazed before being delivered.

The digital as well as the conventional protocols aim to create a well-fitting crown to restore tooth function and esthetics. The digital process reduces the number of appointments, chair time, and laboratory time[3,4] and provides clinical advantages, including digital archiving and an improved fit compared with conventional techniques.[5]

CAD-CAM has been widely integrated into clinical dentistry, particularly in fixed prosthetics. Older intraoral scanning systems often used laser or confocal imaging technology, but many newer systems utilize structured light, optical, or wand-based technologies, offering higher resolution and faster scanning. Newer scanning systems generally offer greater accuracy, faster scanning, better ergonomics, and more sophisticated software program capabilities than their older counterparts.[6–8] Scan accuracy is affected by the quality and calibration of the intraoral scanner, and inadequate scanning skills, patient movement, saliva or blood, and reflective surfaces can affect scanning accuracy. Complex anatomic structures might pose challenges in obtaining accurate scans. Taking care to address these factors helps ensure more accurate intraoral scanning outcomes.[9]

Before integrating new protocols into clinical practice, patient safety and satisfaction, the efficacy of the procedures, and economic costs must be considered.[10] While it is imperative to adopt innovative and effective clinical methods to ensure the best possible therapeutic outcomes for patient care, it is also important to quantify the time and cost of these new interventions.[11] In addition, time and cost are factors that influence a patient's decision with respect to dental prosthetic treatment.[12] However, clinical studies comparing time and cost for conventional and digital workflows in terms of the fabrication of fixed dental prostheses are scarce. Further evidence is needed to demonstrate that restoration using digital systems is more rapid and less costly than the conventional process.

The aim of this systematic review was to analyze and compare the time efficiency and cost of fixed dental prostheses fabricated by using digital and conventional methods from scanning or impression to delivery of the prosthesis. The null hypotheses were that no difference would be found in the clinical and laboratory time spent or the cost of fabricating fixed dental prostheses using the digital or conventional protocol.

## MATERIAL AND METHODS

The selection of articles for the systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P 2015) guidelines.[13] The analysis methods and inclusion criteria were specified in a protocol registered in the Prospective International Register of Systematic Reviews (PROSPERO) CRD42023458734, where no similar protocol was found.

The bibliographic search involved the PubMed and Cochrane databases. The main keywords used were "(Prosthodontic OR restorative dentistry OR denture) AND (CAD CAM OR Digital workflow OR Computer Dentistry OR Digital Design) AND (Economic OR cost OR Financial OR time efficiency)." Filters were applied for reports published between January 2010 and February 2023.

Inclusion criteria were articles written in English, published between January 2010 and February 2023, and referred to the comparison of cost analysis outcomes and/or time efficiency between digital and conventional workflows in the field of fixed prosthodontics. During screening, the articles presenting the following criteria were excluded: articles not written in English, articles presenting in vitro studies, clinical reports, narrative reviews or those based on opinion, articles referring to cost analysis or time efficiency of digital and conventional workflows in other fields such as implant surgery, maxillofacial surgery, maxillofacial prostheses, or orthodontics, purely technical articles, articles dealing with time efficiency or cost analysis of crowns designed and fabricated by dental students, preclinical students, postgraduate students, or prosthodontic students, or articles referring to cost analysis or time efficiency for digital and conventional workflows in removable prosthodontics and implantology.

Two investigators (M.B., N.E.O.) carried out the preliminary search using the keywords and undertook the different steps to select the articles. A spreadsheet (Excel; Microsoft Corp) was created for data extraction and management, and a preliminary pilot form was tested by 2 investigators (M.B., N.E.O.). The following items were collected for data extraction: name of the first author, year of publication, study design, prosthetic discipline, type of prosthesis, groups compared, clinical steps of the digital workflow evaluated, laboratory steps of the digital workflow evaluated, clinical steps of the conventional workflow evaluated, laboratory steps of the conventional workflow evaluated, evaluation criteria for cost analysis, evaluation criteria for time efficiency, conclusions of the comparisons between digital and conventional workflow, reasons for noninclusion, and the language of the manuscript.

Two investigators (N.D., N.E.O.) applied the CONSORT GRADE approach to assess the quality of evidence in the various studies.[14] Each investigator independently assessed and scored the selected studies, and, in the case of disagreement, a discussion between the investigators led to a consensus.[14] The results were synthesized in a brief narrative study to compare time efficiency and cost analysis between digital and conventional workflows for fixed dental prostheses.

## RESULTS

The search carried out in February 2023 identified 909 records in the PubMed database and no additional articles were found in the Cochrane Library or PROSPERO. After eliminating articles published before January 2010, 746 records remained. No duplicates were detected, but 632 records were excluded based on the titles, a further 84 records were excluded based on the exclusion criteria after reading the abstract, and 22 were excluded after reading the full text. A flow chart presenting the selection process of included records according to the PRISMA 2020 flow diagram guidelines[15] is displayed in Figure 1. The search identified 8 articles published between 2010 and 2023[16–23] (Table 1).

The total CONSORT checklist scores for the included items ranged from 19 to 27 out of a maximum possible score of 30. A description of the equipment and materials used in the digital and conventional workflows is shown in Table 2. The cost and time required for the different clinical and/or laboratory steps of conventional and digital workflows are shown in Table 2. A comparison of each stage of clinical and laboratory time for each of the 8 articles is given in Tables 3 and 4.

The time needed to obtain conventional impressions and digital scans for the fabrication of single crowns was documented in 3 articles. Ahrberg et al[16] reported that the quadrant scan time for single crowns with the Lava C.O.S. scanner (10 minutes 21 seconds) was shorter than for a conventional polyether impression (15 minutes 33 seconds).[16] Park et al[21] reported that the quadrant scan time for single crowns with the Cerec Omnicam scanner (7 minutes 29 seconds) and the AEGIS.PO scanner (7 minutes 16 seconds) was shorter than for a conventional polyvinyl siloxane impression (12 minutes 41 seconds) (Table 5). However, Benic et al[17] reported that the time required for a conventional closed-mouth impression with the triple-tray technique (4 minutes 20 seconds) was less than the time needed for digital procedures with the Lava C.O.S. (8 minutes

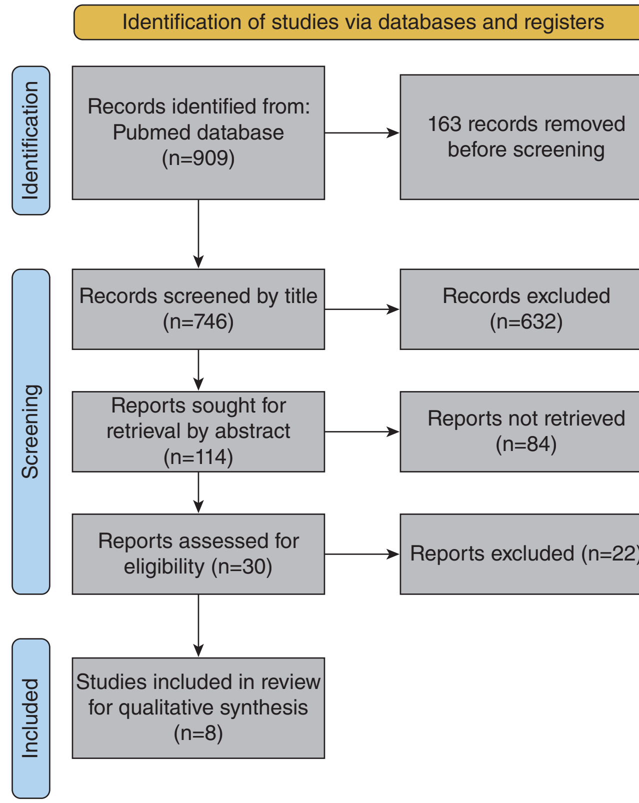


**Figure 1.** Flow chart for study inclusion.

13 seconds), ITero (6 minutes 12 seconds), and Cerec Bluecam (5 minutes 57 seconds) scanners (Table 5).

The time required for complete arch scanning and conventional impression making was evaluated in 2 studies for the fabrication of a 3-unit fixed partial denture. Ahrberg et al[16] reported that scanning with the Lava C.O.S. scanner (15 minutes 33 seconds) was faster than a conventional polyether impression (17 minutes 7 seconds) (Table 5). However, Sailer et al[20] reported that complete arch scans with the Lava C.O.S. (18 minutes 11 seconds), ITero (21 minutes 52 seconds), and Cerec Bluecam (28 minutes 22 seconds) scanners took longer than a conventional complete arch impression (10 minutes 58 seconds) (Table 5).

The time efficiency of digital scans and conventional impressions revealed that the quadrant impressions take less time (10 minutes 21 seconds) than conventional complete arch impressions (15 minutes 33 seconds) (Table 5).[16] Also, the review showed that the application of titanium dioxide powder did not significantly increase the duration of the intraoral scan when fabricating single crowns or 3-unit fixed partial dentures compared with no powdering (Table 5).[17,20]

Concerning the time analysis of the laboratory steps, Zuercher et al[23] reported that the time required by the clinician (5 minutes 07 seconds) to design a single tooth

**Table 1.** References included in qualitative synthesis

| References | Titles | Sample Size | Design |
|---|---|---|---|
| Ahrberg et al, 2016[16] | Evaluation of fit and efficiency of CAD-CAM fabricated ceramic restorations based on direct and indirect digitalization: double-blinded, randomized clinical trial. | Single crowns ceramic zirconia (n=17) 3-unit FDPs (n=8) | Randomized controlled clinical trial |
| Benic et al, 2016[17] | Randomized controlled within-subject evaluation of digital and conventional workflows for fabrication of lithium disilicate single crowns. Part I: digital versus conventional unilateral impressions | Lithium disilicate posterior single crowns (n=10) | Randomized controlled clinical trial |
| Mühlemann et al, 2018[18] | Clinical quality and efficiency of monolithic glass-ceramic crowns in posterior area: digital compared with conventional workflows | Monolithic posterior single crowns of lithium disilicate reinforced glass-ceramic (n=10) | Randomized controlled clinical trial |
| Sailer et al, 2019[20] | Randomized controlled clinical trial of digital and conventional workflows for fabrication of zirconia-ceramic fixed partial dentures. Part I: Time efficiency of complete-arch digital scans versus conventional impressions | 3-unit posterior zirconia-ceramic fixed partial dentures (n=10) | Randomized controlled clinical trial |
| Mühlemann et al, 2019[19] | Randomized controlled clinical trial of digital and conventional workflows for fabrication of zirconia-ceramic posterior fixed partial dentures. Part II: Time efficiency of CAD-CAM versus conventional laboratory procedures | 3-unit posterior zirconia-ceramic fixed partial dentures (n=10) | Randomized controlled clinical trial |
| Park et al, 2020[21] | Clinical evaluation of time efficiency and fit accuracy of lithium disilicate single crowns between conventional impression and digital scan | Lithium disilicate posterior single crowns (n=13) | Clinical trial |
| Cheng et al, 2021[22] | Randomized clinical trial of conventional and digital workflow for fabrication of interim crowns: evaluation of treatment efficiency, fit, and effect of clinician experience | Interim posterior single crowns (SC) (n=40) | Randomized controlled clinical trial |
| Zuercher et al, 2023[23] | Randomized controlled pilot study assessing efficacy, efficiency, and patient-reported outcomes measures of chairside and laboratory single-tooth restorations | Zirconia-reinforced lithium silicate glass–ceramic for posterior single crowns (n=18) | Randomized controlled clinical trial |

restoration using a CAD software program was shorter than that required by a dental laboratory technician (13 minutes) (Table 6).[23]

Mühlemann et al[19] recorded the time taken to fabricate the cast and the 3-unit framework and to carry out the veneering process. They reported that the dental laboratory technician's total working time was 220 ±29 minutes for the Lava COS CAD program and centralized CAM, 217 ±23 minutes for the CARES CAD program and centralized CAM, 262 ±22 minutes for the CEREC Connect CAD and centralized CAM, and 370 ±34 minutes for conventional workflows with a noble metal framework fabricated with the traditional lost-wax technique. The dental laboratory technician spent more time on the conventional workflow than the digital workflow, irrespective of the CAD-CAM system used (Table 6). Cheng et al[22] reported that an interim crown fabricated with a digital workflow required a shorter fabrication time than those fabricated with a conventional workflow involving diagnostic waxing, mold duplication, and vacuum-formed matrices (Table 6).

Concerning the time analysis of the clinical evaluation and chairside adjustment, Mühlemann et al[18] recorded the working time of monolithic single crowns for 4 digital (Lava C.O.S. and CARES CAD software program and centralized CAM: 7:36 ±4:00 minutes; iTero, CARES CAD software program and centralized CAM: 10:55 ±6:14 minutes; Cerec Bluecam, Cerec Connect CAD software program in the laboratory milling unit: 13:03 ±6:43 minutes, and Cerec Bluecam, Cerec Connect CAD software program and Centralized CAM: 09:16 ±4:45 minutes), and 1 conventional (13:53 ±7:31 minutes) workflows. Adjustment time was greater for the conventional and digital workflows followed by laboratory CAM than for the digital workflow with centralized CAM, but they reported no significant difference in treatment times for the 5 groups (Table 7).

Mühlemann et al[19] recorded the clinical chairside time for occlusal adjustments during the fabrication of zirconia-ceramic posterior fixed partial dentures, which ranged from 1.1 ±2.1 minutes for Cerec Connect to 2.2 ±3.7 minutes for Lava C.O.S., with no significant difference between digital and conventional workflows (Table 7).

Zuercher et al[23] reported that chairside adjustment time was statistically significant in favor of the laboratory group (in which a dental laboratory technician designed a restoration using a CAD software program) compared with the chairside workflow (in which a clinician designed a restoration using a CAD software program) for single-tooth restorations. Similarly, clinicians invested less time in finishing and polishing restorations in the laboratory than in chairside restorations (Table 7). Cheng et al[22] reported that interim crown fabrication required significantly less clinical time with the digital system (27.4 ±9 minutes) than with the conventional system (42.6 ±16.2 minutes); however, the clinical time evaluated included intraoral scanning and clinical crown evaluation for the digital system, impression making, interim crown fabrication directly on the teeth, and clinical crown evaluation for the conventional system (Table 7).

**Table 2.** Summary table of groups and outcome variables reported in 8 studies included in systematic review

| References | Digital Workflow | Conventional Workflow | Time Efficiency | Cost Analysis |
|---|---|---|---|---|
| Ahrberg et al, 2016[16] | Computer-aided scan with Lava COS. | Conventional polyether impression with polyether material (Impregum Penta Soft) with monophase technique. | Total working time with each step involved in impression procedure: preparation, impression, impression antagonist, occlusal registration. | NA |
| Benic et al, 2016[17] | Computer-aided scan with:<br>(1) Lava COS, (2) iTero, (3) Cerec BlueCam. | Conventional impression with triple-tray technique and polyvinyl siloxane material. | Time needed for powdering, impressions, and interocclusal record. | NA |
| Mühlemann et al, 2018[18] | (1) Lava C.O.S. scanner and Lava C.O.S. and CARES CAD software, centralized CAM<br>(2) Cadent iTero scanner, CARES CAD software and centralized CAM<br>(3) Cerec Bluecam, Cerec Connect CAD software, and laboratory-based CAM<br>(4) Cerec Bluecam, Cerec Connect CAD software, and Centralized CAM. | Conventional silicone impression followed by a conventional waxing and heat press technique. Ceramic heat pressed using lost-wax technique. | Total treatment time required for both clinical evaluation of crown and chairside adjustments. | NA |
| Sailer et al, 2019[20] | Computer aided impression with:<br>(1) Lava COS, (2) iTero, (3) Cerec BlueCam. | Conventional impression with polyether material (Permadyne; 3M) and conventional workflow. | Time needed for powdering, impressions, and interocclusal record. | NA |
| Mühlemann et al, 2019[19] | (1) Lava C.O.S. CAD software and centralized CAM,<br>(2) Cadent iTero scanner, CARES CAD software and centralized CAM,<br>(3) Cerec Bluecam, Cerec Connect CAD software and centralized CAM | Noble metal framework fabricated by traditional lost-wax technique using high noble alloy. | Time needed for fabrication of cast, 3-unit framework, and veneering process. Chairside time during clinical appointment for evaluation of framework. | NA |
| Park et al, 2020[21] | (1) AEGIS.PO (Digital Dentistry Solution, Seoul, Korea)<br>(2) Omnicam (Sirona, Bensheim, Germany) | Impression with light-body polyvinyl siloxane and putty with one-step technique | Time needed for impression: preparation, impression, impression antagonist, occlusal registration. | NA |
| Cheng et al, 2021[22] | Intraoral scanning (CS 3500; Carestream Dental), digital crown designing and crown fabrication using milling machine and clinical evaluation of crown. | Impression, waxing, duplication of casts, and fabrication of vacuum-formed matrices, fabrication of interim crowns directly on teeth, and clinical evaluation of crown. | Time needed for impressions, fabrication of interim restorations, and clinical evaluation of interim crown. | NA |
| Zuercher et al, 2023[23] | Laboratory workflow LAB: Scan transferred to the dental laboratory via internet Chair workflow CHAIR: the clinician continued with the design of the restoration using a CAD Software program | | Time needed to design restoration with CAD software program, chairside adjustment time, and chairside finishing time after cementation. | Question on importance of costs relative to esthetics: "*what is more important to you: the costs or esthetics of the crown*?": −5 (high for costs), 0 (costs and esthetics equally important) and 5 (high for esthetics). |

NA, not applicable

**Table 3.** Time analysis of clinical and laboratory steps for 8 studies included in systematic review

| References | Digital Workflows | | Conventional Workflows | |
|---|---|---|---|---|
| | Time Analysis for Clinical Steps | Time Analysis for Laboratory Steps | Time Analysis for Clinical Steps | Time Analysis for Laboratory Steps |
| Ahrberg et al, 2016[16] | Intraoral scanning time<br>1. Preparation: Powdering<br>2. Impression: Computer-aided scan of prepared teeth: quadrant scan capturing prepared tooth.<br>3. Impression antagonist: computer-aided scan of opposing teeth: Scan capturing opposing quadrant.<br>4. Occlusal registration: Scan capturing buccal of these quadrants in intercuspal position. | NE | Impression time<br>1. Preparation with stock tray individualization metal stock trays selected and individualized with silicone stops till application of adhesive.<br>2. Impression: Polyether material Impregum Penta Soft with Entamix machine and monophase technique.<br>3. Impression antagonist with alginate material.<br>4. Occlusal registration in maximum intercuspation using Protemp 4. | NE |
| Benic et al, 2016[17] | Intraoral scanning time<br>1. Preparation: Powdering<br>2. Impression + interocclusal record: Digital scan Quadrant scans + occlusal registration | NE | Impression time<br>1. Impression + interocclusal record: Conventional unilateral impression and interocclusal record performed simultaneously. Conventional unilateral impression with triple tray technique and polyvinyl siloxane material. Time recorded from beginning of mixing procedure up to end of tray removal from patient's mouth. | NE |
| Mühlemann et al, 2018[18] | Clinical evaluation of crown and chairside adjustments: Internal fit checked and adjusted if needed with silicone material<br>Outer surface adjusted if interproximal contact points too tight, and if occlusal contact points too strong. | NE | Clinical evaluation of the crown and chairside adjustments: Internal fit checked and adjusted if needed with silicone material.<br>Outer surface adjusted if interproximal contact points too tight, and if occlusal contact points too strong. | NE |
| Sailer et al, 2019[20] | Intraoral scanning time<br>1-Preparation: Powdering<br>2-Impression + interocclusal record: Complete arch digital scans + occlusal registration | NE | Impression time<br>1-Impression + interocclusal record:<br>Time recorded from beginning of mixing procedure up to end of tray removal from patient's mouth.<br>Conventional impressions with light- and regular-body polyether materials and metal stock impression trays.<br>Occlusal registration with silicone occlusal registration paste in maximum intercuspal position. Impression of opposing arch with alginate. | NE |
| Mühlemann et al, 2019[19] | Chairside time during clinical appointment for evaluation of framework<br>1-Clinical Evaluation Time<br>2-Chairside Adjustment Time | Time for cast design: time for virtual design of definitive cast<br>Shipping time of cast: time until shipping of definitive cast from manufacturer to dental laboratory<br>Time for framework design: CAD software program of each digital workflow used to design framework of 3-unit FPD<br>Shipping time of frameworks: Shipping time of sintered CAD-CAM frameworks from manufacturer's milling center to dental laboratory.<br>Ceramic Veneering: manual working time for adaptation of framework to cast and veneering of framework (by dental laboratory technician). | Chairside time during the clinical appointment for the evaluation of the framework<br>1-Clinical Evaluation Time<br>2-Chairside Adjustment Time | Time for cast design: impressions poured and trimmed. After they had been embedded in a prefabricated tray, the definitive casts were mounted in an articulator.<br>Shipping time of cast: time until shipping of the definitive cast from the centralized manufacturer to the dental laboratory<br>Time for framework design<br>Shipping time of fabricated frameworks: Noble metal framework fabricated by means of the traditional lost-wax technique using high noble alloy<br>Ceramic Veneering: manual working time for adaptation of framework to |

**Table 3** *(Continued)*

| References | Digital Workflows | | Conventional Workflows | |
|---|---|---|---|---|
| | Time Analysis for Clinical Steps | Time Analysis for Laboratory Steps | Time Analysis for Clinical Steps | Time Analysis for Laboratory Steps |
| | | | | cast and the veneering of framework (by dental laboratory technician). |
| Park et al, 2020[21] | Intraoral scanning time<br>Time to obtain digital scans recorded from software program startup to data processing: Software start-up, powdering, abutment scan, antagonist scan, occlusal scan, data processing | NA | Impression time<br>Time to obtain conventional impression recorded from beginning of application of tray adhesive to end of occlusal material removal from patient's mouth: applying tray adhesive, abutment impression, antagonist impression, occlusal registration. | NA |
| Cheng et al, 2021[22] | Time for intraoral scanning and clinical evaluation of interim crown | Time for digital designing and fabrication using milling machine | Impression making, fabrication of interim crowns directly on teeth, and clinical evaluation of crown | Diagnostic waxing, duplication of casts, and fabrication of vacuum-formed matrices |
| Zuercher et al, 2023[23] | Time for clinician to design restoration with CAD software program | Time needed to design restoration with CAD software program | 1-Chairside adjustment time<br>2-Chairside finishing time after cementation | |

NE, not evaluated

For cost analysis, the importance of cost relative to esthetics on a visual analog scale was reported in 1 article not to be significant between chairside (in which a clinician designs a restoration with CAD software program) and laboratory (in which a laboratory technician designs a restoration with CAD software program) workflows for single-tooth restorations.[23] However, no articles were found that compared the cost of fixed prostheses made with digital and conventional processes.

## DISCUSSION

This review focused on the comparison of working times and manufacturing costs for single crowns and 3-unit fixed dental prostheses using digital and conventional workflows. In term of laboratory steps, the null hypothesis that no difference would be found in clinical and laboratory time spent fabricating fixed dental prostheses using the digital or conventional protocol was rejected, as the review showed that digital workflows can reduce the time needed for laboratory steps in the manufacture of fixed prostheses. The dental laboratory technician spent more time on the conventional workflow than the digital workflow for the 3-unit framework and veneering process,[19] as well as for an interim crown.[22] For chairside time, 2 studies reported that the impression time for the fabrication of a single crown was longer for a conventional impression than for a digital scan,[16,21] and 1 study reported that a conventional impression was faster than a digital scan.[17] For Ahrberg et al[16] and Park et al,[21] the recorded time for conventional impressions involved successive phases, starting with the selection and individualization of impression trays, with stops following the application of adhesive and impression material, for the registration of the impression itself and the antagonist of the impression, and then to register the occlusion. For Benic et al,[17] the time recording for a conventional closed-mouth impression (triple-tray technique) began at the start of the mixing procedure and concluded with the removal of the tray from the patient's mouth. This technique has been reported to be accurate and less time consuming[24] but is contraindicated for extensive restorations. As conventional impression methods differed for these 3 studies, the impression time appears to depend on the method used.

In terms of impression time for the fabrication of a 3-unit FDP, Ahrberg et al[16] reported that conventional impression took longer than the digital scan. However, Sailer et al[20] reported that conventional complete arch impressions were less time consuming than the digital scan procedures. Hence, the steps involved in defining working time for making impressions varied across studies. This review highlights the absence of a standardized conventional workflow and a variety of digital

**Table 4.** Summary of included studies

| Study | Restorations | Outcomes | Steps of the Digital Workflow Analyzed | | | Steps of the Conventional Workflow Analyzed | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Clinical** | **Laboratory** | **Clinical** | **Clinical** | **Laboratory** | **Clinical** |
| Ahrberg et al, 2016[16] | Single crowns (n=17)<br>3-unit FDP (n=8) | Working time | Intraoral scanning time<br>1. Powdering<br>2. Scanning<br>3. Scanning antagonist<br>4. Occlusal registration<br>5. Total time | NE | NE | Impression<br>1. Stock tray individualization<br>2. Impression<br>3. Impression antagonist<br>4. Occlusal registration<br>5. Total time | NE | NE |
| Benic et al, 2016[17] | Single crowns (n=10) | Working time | Intraoral scanning time<br>1. Preparation<br>2. Scanning / interocclusal record<br>3. Total time | NE | NE | Impression<br>1. Impression / interocclusal record<br>2. Total time | NE | NE |
| Mühlemann et al, 2018[18] | Single crowns (n=10) | Working time | NE | NE | Time for clinical evaluation of crown / chairside adjustments | NE | NE | Clinical evaluation of crown / chairside adjustments |
| Sailer et al, 2019[20] | 3-unit FDP (n=10) | Working time | Intraoral scanning time<br>1. Preparation<br>2. Scanning / interocclusal record<br>3. Total time | NE | NE | Impression<br>1. Impression / interocclusal record<br>2. Total time | NE | NE |
| Mühlemann et al, 2019[19] | 3-unit FDP (n=10) | Working time | NE | Time for fabrication of cast, 3-unit framework, and veneering process | Chairside time during clinical appointment to assess framework | NE | Time for the fabrication of the cast, the 3-unit framework, and veneering process | Chairside time during the clinical appointment to assess the framework |
| Park et al, 2020[21] | Single crowns (n=13) | Working time | Intraoral scanning time<br>Software start-up, powdering, abutment scan, antagonist scan, occlusal scan, data processing | NE | NE | Impression time<br>applying tray adhesive, abutment impression, antagonist impression, occlusal registration. | NE | NE |
| Cheng et al, 2021[22] | Interim single crowns (n=40) | Working time | Intraoral scanning | Designing and fabrication of interim crown | Clinical evaluation | Impression making | Waxing and fabrication of matrices | Fabrication of crowns directly on teeth, and clinical evaluation |
| Zuercher et al, 2023[23] | Single crowns (n=18) | -Working time<br>- Costs relative to esthetics | Time for clinician to design restoration with CAD software program | Time needed for dental laboratory technician to design restoration with CAD software program | 1-Chairside adjustment time<br>2-Chairside finishing time after cementation | NE | NE | NE |

FDP, fixed dental prosthesis; NE, not evaluated; SC, single crown.

**Table 5.** Time analysis of digital and conventional impression steps (minutes: seconds)

| Single Crowns | Digital 1: Lava C.O.S. | | | | Digital 2: ITero | Digital 3: Cerec Bluecam | | Digital 4: Cerec Omnicam | Digital 5: AEGIS.PO | Conventional Impression | | | | *P* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ahrberg et al, 2016[16] | Phase 1: Application of Titanium Dioxide Powder | Phase 2: Quadrant Scan | Phase 3: Opposing Quadrant | Phase 4: Occlusal Records | | | | | | Phase 1: Before the Application of Tray Adhesive | Phase 2: Polyether Impregum with Pentamix Machine and Monophase Technique | Phase 3: Opposing Impressions with Alginate | Phase 4: Occlusal Registration in Maximum Intercuspal Position | |
| | 1:26<br>10:21 | 5:25 | 2:52 | 0:42 | | | | | | 4:25<br>15:33 | 7:01 | 2:48 | 1:33 | NA |
| Benic et al, 2016[17] | Application of titanium dioxide powder | Quadrant scans + Occlusal records | | | Quadra-nt scans + Occlusal records | Applic-ation of tita-nium dioxide powder | Quadrant scans + Occlusal records | | | Conventional unilateral impression and interocclusal record performed simultaneously with the closed-mouth (triple-tray) technique.Polyvinyl siloxane (A-silicone) light and regular body (President) for impression. | | | | |
| | 0:54 ±0:14 | 7:19 ±3:16 | | | | 1:06 ±0:37 | 4:52 ±0:50 | | | | | | | |
| | 8:13 ±3:13[c] | | | | 6:12 ±2:06[b] | 5:57 ±0:55[b] | | | | 4:20 ±1:06[a] | | | | <.05 |
| Park et al, 2020[21] | | | | | | | | Powdering, Quadrant scans, Abutment, antagonist, and interoc-clusal records | Application of titanium dioxide powder, quadrant scans, Abutment, antagonist, and interoc-clusal records | Quadrant impression with perforated plastic tray, application of tray adhesive.Impression with light-body polyvinyl siloxane (Imprint II Garant) and putty (Exaflex Putty) using 1-step technique.Opposing arch impression with alginate.Interocclusal record with polyvinyl siloxane (O-bite). | | | | |
| | | | | | | | | 7:29 ±2:03 | 7:16 ±1:50 | 12:41 ±1:16 | | | | <.001 |
| 3-units Fixed Dental Prostheses | Digital 1: Lava C.O.S. | | | | Digital 2: Itero | Digital 3: Cerec Bluecam | | Digital 4: Cerec Omnicam | Digital 5: AEGIS.PO | Conventional impression | | | | *P* |
| Ahrberg et al, 2016[16] | Phase 1: Application of titanium dioxide powder | Phase 2: Full-arch scan | Phase 3: opposing quadrant | Phase 4: buccal aspect in maximum intercuspal position | | | | | | Phase 1: before the application of tray adhesive | Phase 2: polyether Impregum with Pentamix machine and monophase technique | Phase 3: opposing impressions with alginate | Phase 4: occlusal registration in maximum intercuspal position | |
| | 4:25<br>15:33 | 7:01 | 2:48 | 1:33 | | | | | | 4:38<br>17:07 | 8:09 | 3:29 | 1:20 | NA |

**Table 5** (*Continued*)

| Single Crowns | Digital 1: Lava C.O.S. | | Digital 2: ITero | Digital 3: Cerec Bluecam | | Digital 4: Cerec Omnicam | Digital 5: AEGIS.PO | Conventional Impression | *P* |
|---|---|---|---|---|---|---|---|---|---|
| Sailer et al, 2019[20] | Application of titanium dioxide powder | complete arch scans and interocclusal records | Complete arch scans and interocclusal records | Application of titanium dioxide powder | Complete-arch scans and occlusal records | | | Impressions with light and regular body polyether (Permadyne) and metal stock impression trays.Occlusal registration with silicone (Preciform) in maximum intercuspal position.Impression of opposing arch with alginate. | |
| | 1:20 ±0:35 | 16:50 ±8:49 | | 1:36 ±0:25 | 26:43 ±9:02 | | | | |
| | 18:11 ±8:43[a,b] | | 21:52 ±8:43[b] | 28:22 ±9:18[b] | | | | 10:58 ±3:01[a] | <.05 |

NA, not available.

Different letters indicate significance difference between groups (*P*<.05).

**Table 6.** Time analysis of laboratory steps (minutes: seconds)

| Mean ±SD (Minutes: Seconds) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Groups** | **Designing and or Fabrication** | **Time for Cast Design Time for Virtual Design of Definitive Cast** | **Shipping Time of Cast Time Until Shipping of Definitive Cast from Centralized Manufacturer to Dental Laboratory** | **Time for Framework Design CAD Software Program of Each Digital Workflow Used to Design Framework of 3-unit FPD** | **Ceramic Veneering Manual Working Time for the Adaptation of the Framework to Cast and Veneering of Framework** | **Shipping Time of Frameworks Shipping Time of Sintered CAD-CAM Frameworks from Manufacturer's Milling Center to Dental Laboratory** | **Total Working Time for Dental Laboratory Technician** |
| Single crowns Zuercher et al, 2023[23] | Laboratory workflow | Scan transferred to dental laboratory via internet | | | | | | |
| | Mean and 95% CI in min:s | 13:00 (10:30; 14:30) | | | | | | |
| | Chair workflow | Clinician continued the design of the restoration using CAD Software program | | | | | | |
| | Mean and 95% CI in min:s | 5:07 (3:02; 7:58) | | | | | | |
| | *P* | <.001 | | | | | | |

**Table 6** (*Continued*)

| Mean ±SD (Minutes: Seconds) | Groups | Designing and or Fabrication | Time for Cast Design Time for Virtual Design of Definitive Cast | Shipping Time of Cast Time Until Shipping of Definitive Cast from Centralized Manufacturer to Dental Laboratory | Time for Framework Design CAD Software Program of Each Digital Workflow Used to Design Framework of 3-unit FPD | Ceramic Veneering Manual Working Time for the Adaptation of the Framework to Cast and Veneering of Framework | Shipping Time of Frameworks Shipping Time of Sintered CAD-CAM Frameworks from Manufacturer's Milling Center to Dental Laboratory | Total Working Time for Dental Laboratory Technician |
|---|---|---|---|---|---|---|---|---|
| 3-units FDP Mühlemann et al, 2019[19] | Digital 1: Lava C.O.S. CAD software (3M) and centralized CAM | | 13 ±3[b] | 9306 ±223[b] | 27 ±26[a] | 181 ±13[a] | 5700 ±2499[b] | 220 ±29[ab] |
| | Digital 2: CARES CAD software (Institut Straumann AG) and centralized CAM | | 2 ±1[a] | 6194 ±1587[b] | 20 ±9[a] | 195 ±19[a] | 5978 ±1778[b] | 217 ±23[a] |
| | Digital 3: CEREC Connect CAD software (Dentsply Sirona) and centralized CAM | | 5 ±4[a] | 6553 ±3277[b] | 38 ±8[a] | 219 ±16[b] | 8523 ±3415[b] | 262 ±22[b] |
| | Conventional workflow: Noble metal framework fabricated with traditional lost-wax technique | | 37 ±5[c] | 135[a] | 138 ±14[b] | 195 ±25[a] | 285[a] | 370 ±34[c] |
| | *P* | | .001 | <.001 | <.001 | <.05 | <.001 | <.001 |
| Interim single crowns Cheng et al, 2021[22] | Digital workflow | Digital crown designing and crown fabrication using milling machine 44:1 ±11:30 | | | | | | |
| | Conventional workflow | Diagnostic waxing, duplication of casts and fabrication of vacuum-formed matrices 86:18 ±31:36 | | | | | | |
| | *P* | .001 | | | | | | |

95% CI, 95% confidence interval; FDP, fixed dental prostheses; SD, standard deviation.

Different letters indicate significance difference between groups (*P*<.05).

**Table 7.** Time analysis of the clinical evaluation and chairside adjustment (minutes: seconds)

**Mean ±SD (Minutes: Seconds)**

| Articles | Groups for Comparison | Working Time for Chairside Adjustments | Description for Chairside Adjustments | Finishing Time After Cementation |
|---|---|---|---|---|
| Single crowns Mühlemann S et al, 2018[18] | Lava C.O.S. scanner<br>Lava C.O.S. and CARES CAD software program<br>Centralized CAM | 7:36 ±4:00 | 1) Internal fit of crown evaluated with silicone material and adjusted, if needed;<br>(2) External surface of crowns adjusted if interproximal contact points too tight;<br>(3) External surface of crowns adjusted if occlusal contacts too strong. | NE |
| | Cadent iTero scanner<br>CARES CAD software program<br>Centralized CAM | 10:55 ±6:14 | | |
| | Cerec Bluecam<br>Cerec Connect CAD software program<br>Laboratory-based CAM (in Laboratory milling unit) | 13:03 ±6:43 | | |
| | Cerec Bluecam,<br>Cerec Connect CAD software program<br>Centralized CAM | 09:16 ±4:45 | | |
| | Conventional silicone impression<br>Conventional waxing<br>Heat press technique | 13:53 ±7:31 | | |
| | *P* | >0.05 | | |
| Single crowns Zuercher et al, 2023[23] | Laboratory workflow (technician design restoration with CAD software program) | 7:18 95% CI (5:44; 7:22) | Adjustment of occlusion and contact points if needed of single tooth restoration. | 16:31 95% CI (8.85; 21.44) |
| | Chair workflow (clinician design restoration with CAD software program) | 0 95% CI (0; 2:30) | | 7:00 95% CI (3:51; 12:32) |
| | *P* | 0.003 | | 0.018 |
| 3-units FDP Mühlemann S et al, 2019[19] | Lava C.O.S.<br>CAD software program<br>Centralized CAM | 2:12 ±3:42 | Chairside clinical time for occlusal adjustments for fabrication of posterior fixed zirconia-ceramic partial dentures. | NE |
| | Cadent iTero scanner<br>CARES CAD software program<br>Centralized CAM | 1:54 ±2:48 | | |
| | Cerec Bluecam<br>Cerec Connect CAD software program<br>Centralized CAM | 1:06 ±2:06 | | |
| | Framework fabricated with traditional lost-wax technique using high noble alloy | 1:30 ±2:18 | | |
| | *P* | >0.05 | | |
| Interim crown Cheng et al, 2021[22] | Digital workflow: crown designing and fabrication using milling machine | 27:24 ±9:00 | Clinical evaluation using California Dental Association criteria and World Dental Federation's recommendation with addition of crown morphology. Assessment of marginal fit with dental explorers, of proximal contacts with dental floss, and occlusal contacts with articulating film. (Also included time for impression or intraoral scan). | NE |
| | Conventional workflow: diagnostic waxing, duplication of casts and fabrication of vacuum-formed matrices | 42:36 ±16:12 | | |
| | *P* | <0.001 | | |

95% CI, 95% confidence interval; FDP, fixed dental prostheses; NE, not evaluated; SD, standard deviation.

workflow techniques to compare working time between digital scans and conventional impressions. Therefore, the null hypothesis for working time for making impressions was not rejected. Spraying with titanium oxide powder is an additional step that can enhance intraoral scanning by improving surface reflection, enabling more accurate and detailed images to be captured.[25] Powder spraying can shorten scan times by ensuring better quality scans at the first attempt, reducing the need for repeated scans. However, the systematic review did not reveal that powder spraying could influence the duration of intraoral scanning compared with not powder spraying. Analysis of the length of time for clinical evaluation and chairside adjustment showed no differences between conventional and digital workflows for single crowns[18] or 3-unit FDPs.[19]

The null hypothesis that no difference would be found in the cost of a fixed prosthesis fabricated with the digital or conventional protocol was not rejected. However, only 1 report assessed the importance of cost versus esthetics on a visual analog scale.[23] Therefore, the cost effectiveness outcome was not sufficiently evaluated. The authors are unaware of a previous review that identified articles comparing the time efficiency and cost effectiveness of conventional and digital workflows for the fabrication of fixed prostheses. A total of 8 articles were examined, of which 7 were randomized controlled clinical trials (RCTs), including crossover trials. The RCT minimizes the risk of confounding factors.[26] Crossover trials have high statistical power, interparticipant variability is eliminated from the comparison between groups, and the effect of covariates is reduced.[27]

Limitations of this systematic review included that the types of treatment evaluated did not include long-span FDPs, onlays, or veneers. In addition, 5 digital systems were used in the selected articles (Lava C.O.S., iTero, Cerec Bluecam, Cerec Omnicam, AEGIS. PO) using quadrant scans for single crowns and complete-arch scanning for FDPs. Other digital systems available on the market were not evaluated as part of this study. Further studies are needed to assess the effect of the method on recording time and on the cost effectiveness of conventional and digital workflows for the fabrication of tooth-supported restorations.

## CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. The digital pathway for the fabrication of fixed prostheses can shorten the laboratory processing time.
2. Conventional impression time may vary depending on the technique used.
3. Conventional impression-making techniques were diverse in the studies reviewed.

## REFERENCES

1. Chang HS, Peng YT, Hung WL, Hsu ML. Evaluation of marginal adaptation of Co—Cr—Mo metal crowns fabricated by traditional method and computer-aided technologies. *J Dent Sci*. 2019;14:288–294.
2. Haidar ZS. Digital dentistry: Past, present, and future. *Digital Medicine and Healthcare Technology* 2023. https://doi.org/10.5772/DMHT.17
3. Mubaraki MQ, Moaleem MMA, Alzahrani AH, et al. Assessment of conventionally and digitally fabricated complete dentures: A comprehensive review. *Materials (Basel)*. 2022;15:3868.
4. Janeva NM, Kovacevska G, Elencevski S, Panchevska S, Mijoska A, Lazarevska B. Advantages of CAD/CAM versus conventional complete dentures - A review. *Open Access Maced J Med Sci*. 2018;6:1498–1502.
5. Arakawa I, Al-Haj Husain N, Srinivasan M, Maniewicz S, Abou-Ayash S, Schimmel M. Clinical outcomes and costs of conventional and digital complete dentures in a university clinic: A retrospective study. *J Prosthet Dent*. 2022;128:390–395.
6. Bencharit S, Clark W, Stoner L, Chiang G, Sulaiman T. Recent Advancements in CAD/CAM Same-Day Dentistry in Practice and Education. 2021.
7. Davidowitz G, Kotick PG. The use of CAD/CAM in dentistry. *Dent Clin North Am*. 2011;55:559–570. (ix).
8. Suganna M, Kausher H, Tarek Ahmed S, et al. Contemporary evidence of CAD-CAM in dentistry: A systematic review. *Cureus*. 2022;14:e31687.
9. Drancourt N, Auduc C, Mouget A, et al. Accuracy of conventional and digital impressions for full-arch implant-supported prostheses: An in vitro study. *J Pers Med*. 2023;13:832.
10. Beauchemin M, Cohn E, Shelton RC. Implementation of clinical practice guidelines in the healthcare setting: A concept analysis. *ANS Adv Nurs Sci*. 2019;42:307.
11. Srinivasan M, Gjengedal H, Cattani-Lorente M, et al. CAD/CAM milled complete removable dental prostheses: An in vitro evaluation of biocompatibility, mechanical properties, and surface roughness. *Dent Mater J*. 2018;37:526–533.
12. Shrirao ND, Deshmukh SP, Pande NA, Radke UM. An evaluation of patient's decisions regarding dental prosthetic treatment. *J Indian Prosthodont Soc*. 2016;16:366–371.
13. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*. 2015;4:1.
14. Cuschieri S. The CONSORT statement. *Saudi J Anaesth*. 2019;13:S27–S30.
15. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
16. Ahrberg D, Lauer HC, Ahrberg M, Weigl P. Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: A double-blinded, randomized clinical trial. *Clin Oral Investig*. 2016;20:291–300.
17. Benic GI, Mühlemann S, Fehmer V, Hämmerle CHF, Sailer I. Randomized controlled within-subject evaluation of digital and conventional workflows for the fabrication of lithium disilicate single crowns. Part I: Digital versus conventional unilateral impressions. *J Prosthet Dent*. 2016;116:777–782.
18. Mühlemann S, Benic GI, Fehmer V, Hämmerle CHF, Sailer I. Clinical quality and efficiency of monolithic glass ceramic crowns in the posterior area: Digital compared with conventional workflows. *Int J Comput Dent*. 2018;21:215–223.
19. Mühlemann S, Benic GI, Fehmer V, Hämmerle CHF, Sailer I. Randomized controlled clinical trial of digital and conventional workflows for the fabrication of zirconia-ceramic posterior fixed partial dentures. Part II: Time efficiency of CAD-CAM versus conventional laboratory procedures. *J Prosthet Dent*. 2019;121:252–257.
20. Sailer I, Mühlemann S, Fehmer V, Hämmerle CHF, Benic GI. Randomized controlled clinical trial of digital and conventional workflows for the fabrication of zirconia-ceramic fixed partial dentures. Part I: Time efficiency of complete-arch digital scans versus conventional impressions. *J Prosthet Dent*. 2019;121:69–75.
21. Park JS, Lim YJ, Kim B, Kim MJ, Kwon HB. Clinical evaluation of time efficiency and fit accuracy of lithium disilicate single crowns between conventional and digital impression. *Materials (Basel)*. 2020;13:5467.

22. Cheng CW, Ye SY, Chien CH, Chen CJ, Papaspyridakos P, Ko CC. Randomized clinical trial of a conventional and a digital workflow for the fabrication of interim crowns: An evaluation of treatment efficiency, fit, and the effect of clinician experience. *J Prosthet Dent*. 2021;125:73–81.
23. Zuercher AN, Ioannidis A, Hüsler J, Mehl A, Hämmerle CHF, Thoma DS. Randomized controlled pilot study assessing efficacy, efficiency, and patient-reported outcomes measures of chairside and labside single-tooth restorations. *J Esthet Restor Dent*. 2023;35:74–83.
24. Copoulos PC. The “check-bite” method in fixed prosthodontics. *J Prosthet Dent*. 1969;21:333–337.
25. Palousek D, Omasta M, Koutny D, Bednar J, Koutecky T, Dokoupil F. Effect of matte coating on 3D optical measurement accuracy. *Opt Mater*. 2015;40:1–9.
26. Munnangi S, Boktor SW. Epidemiology of Study Design. 2023. StatPearls [Internet]. Treasure Island (FL). StatPearls Publishing,; 2023.
27. Lim CY, In J. Considerations for crossover design in clinical study. *Korean J Anesthesiol*. 2021;74:293–299.

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