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SYSTEMATIC REVIEW

Comparative analyses of time efficiency and cost in fabricating fixed implant-supported prostheses in digital, hybrid, and conventional workflows: A systematic review and meta-analysis

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ABSTRACT

Statement of problem. Economic considerations affect whether new technologies are adopted in dental practice. Limited evidence exists regarding the time and cost efficiency of different workflows for fabricating implant-supported restorations.

Purpose. The purpose of this systematic review and meta-analysis was to compare the time and cost involved in fabricating fixed implant-supported prostheses using digital, hybrid, and conventional methods throughout the entire prosthetic treatment by analyzing both clinical and laboratory steps.

Material and methods. A systematic review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)-P 2015 guidelines. The methods and inclusion criteria were specified in a protocol registered with the International Prospective Register of Systematic Reviews (PROSPERO) (registration number CRD42023458734). The databases PubMed, Cochrane, and PROSPERO were searched using keywords: (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 selected articles independently.

Results. A qualitative synthesis of 12 articles published from 2010 to 2023 showed that digital scans took less time than conventional impressions ($P<.05$) in 7 out of 9 articles. Additionally, 8 articles revealed significant reductions in laboratory working time with digital workflows, intermediate times with hybrid workflows, and longer times with conventional workflows ($P<.001$). Meta-analysis confirmed the time efficiency of digital scanning over conventional impressions (Hedges g=1.65, 95% CI [0.33, 2.98]) and a substantial reduction in laboratory time with digital workflows compared with other workflows (Hedges g=6.55, 95% CI [2.69; 10.42]). However, no significant difference was found in adjustment time between digital and other workflows (Hedges g=0.91, 95% CI [−0.72; 2.55]). Direct laboratory costs were observed to be higher in conventional workflows compared with hybrid or digital workflows, with hybrid workflows also showing elevated costs compared with digital workflows ($P<.05$).

Conclusions. The digital workflow demonstrates potential benefits in reducing scan time, laboratory processing time, and direct laboratory costs for implant-supported restorations in partial edentulism. Further research is needed to validate these findings, particularly for long-span implant-supported fixed partial prostheses. (J Prosthet Dent 2025;133:689-712)

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Clinical Implications

Time and cost significantly impact a patient's decision on implant-supported restorations. A cast-free digital workflow demonstrates potential benefits in reducing scan time, laboratory processing time, and direct laboratory costs for implant-supported restorations compared with hybrid or conventional pathways. Further clinical studies are required to explore outcomes for long-span implant-supported prostheses.

The conventional workflow, involving impression-making, impression posts, gypsum definitive casts, and the lost wax technique, has long been considered the standard in the production process for fixed implant-supported restorations.[1] However, the conventional workflow is associated with economic and technical challenges associated with time-consuming manufacturing steps, costly resources and equipment, and an extensive list of materials. Impression making also results in patient discomfort, including gagging and taste irritation.[2]

The completely digital workflow is an innovative alternative to the conventional pathway and involves cast-free processes.[3] The completely digital workflow consists of acquisition of the implant with an intraoral scanner (IOS) by placing a scan body capable of transferring the implant's spatial position into a computer-aided design (CAD) software program.[4] The resulting scanning data are saved as standard tessellation language (STL) files, facilitating their use in computer-assisted design and manufacturing (CAD-CAM) workflows. During the CAD process, the dental laboratory technician replaces the scan body mesh with data from the implant library, enabling the design of the restoration.[5] Subsequently, restorations are milled directly from monolithic blocks of lithium disilicate or zirconia and bonded to prefabricated[6–8] or custom[9] titanium-base abutments. While prefabricated abutments for screw-retained restorations are considered the first choice in digital workflows, they are not appropriate in complex situations.[3,10,11] Cement-retained restorations with custom abutments and cast-free processes are an alternative in the digital workflow.[12,13]

The hybrid workflow, also referred to as mixed conventional-digital workflow, combines conventional and digital techniques for designing and fabricating prostheses.[7] This method optimizes the advantages of conventional and CAD-CAM methods to achieve high-quality dental restorations. Hybrid workflow could include the use of digital scans, which can be transferred to a physical cast, and the laboratory production of the definitive restoration can be conventional. This process can also include a laboratory scan of conventionally fabricated stone casts, followed by CAD-CAM fabrication of the definitive restoration. The specific components and steps of hybrid workflow can vary depending on the dental procedure, materials, and preferences of the clinician and dental laboratory technician.[6,8,13]

Scan accuracy depends on the quality and calibration of IOSs. Factors that can affect scanning accuracy include insufficient scanning skills, complex anatomic structures, patient movement, presence of saliva or blood, and reflective surfaces.[14–16] Before incorporating new protocols into clinical practice, considerations such as patient safety and satisfaction, efficacy of procedures, and economic costs need to be evaluated.[17] While it is crucial to adopt innovative and effective clinical methods for optimal therapeutic outcomes, it is equally important to assess the time and cost implications of these new interventions.[18] Additionally, time and cost significantly influence patients' decisions regarding dental prosthetic treatment.[19] Evidence on the time and cost efficiency of different treatment workflows for implant-supported restorations are sparse.[20] Time and cost analyses are presumed to be of significant interest to patients, healthcare providers, third-party systems, and society.[21]

This systematic review and meta-analysis aimed to compare the time efficiency and cost of fabricating fixed dental implant-supported restorations for partial edentulism using digital, hybrid, and conventional method, throughout the entire prosthetic treatment, including scanning or impression, laboratory techniques, and prosthesis delivery. The null hypotheses were that no differences would be observed in clinical and laboratory times or costs for fabricating dental implant prostheses using digital, hybrid, or conventional workflows.

MATERIAL AND METHODS

The article selection adhered to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-P 2015).[22] The protocol, which detailed the analysis methods and inclusion criteria, was registered with the Prospective International Register of Systematic Reviews (PROSPERO), CRD42023458734, and no similar protocol was identified. The bibliographic search included PubMed and Cochrane databases, using the following keywords (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 to consider reports published between January 2010 and February 2023.

Inclusion criteria were articles written in English, published between January 2010 and February 2023, and pertaining to the comparison of cost analysis outcomes and/or time efficiency between digital, hybrid, and/or conventional workflows in fixed dental implants prostheses. Exclusion criteria were articles not written in English, in vitro studies, clinical reports, narrative reviews, or opinion-based articles, articles focusing on cost analysis or time efficiency in other fields (implant surgery, maxillofacial surgery, maxillofacial prostheses, or orthodontics), purely technical articles, articles addressing time efficiency or cost analysis of crowns designed and fabricated by dental, preclinical, postgraduate, or prosthodontic students, and articles related to cost analysis or time efficiency in digital and conventional workflows in removable and fixed dental prostheses.

Two investigators (M.B., N.E.O.) conducted the initial search using the specified keywords and performed the article selection process. Data extraction and management spreadsheets were created (Excel; Microsoft Corp), and a preliminary pilot form was tested by the same investigators. The following information was collected during data extraction: first author's name, publication year, study design, prosthetic discipline, type of prosthesis, groups compared, clinical steps of digital, hybrid, and/or conventional workflows, laboratory steps of digital, hybrid, and/or conventional workflows, evaluation criteria for cost analysis, evaluation criteria for time efficiency, conclusions about comparisons between workflows, reasons for noninclusion, and language of the manuscript.

Two investigators (N.E.O., N.D.) used the Consolidated Standards of Reporting Trials (CONSORT) GRADE approach to evaluate the quality of evidence for the selected studies.[23] Each investigator independently assessed and scored each article, and, in case of disagreement, discussions were held to reach a consensus. The findings were synthesized in a systematic review comparing the time efficiency and cost analysis of digital, hybrid, and/or conventional workflows for fixed implant-supported restorations. Three meta-analyses were conducted to quantify the mean time difference in impression time, laboratory active working time, and clinical adjustment time among workflows, assess heterogeneity across studies, and evaluate the presence of publication bias. Statistical analyses were performed using a workbook (Meta-Essentials for Excel; Microsoft Corp). For each study, mean values, sample sizes, and standard deviations were extracted for each workflow. Effect size with 95% confidence interval was calculated and represented using forest plots. Heterogeneity among included studies was assessed using the Q statistic and I^2 statistic. The Q statistic tested the null hypothesis that all studies share a common effect size, while the I^2 statistic quantified the percentage of total variation across studies due to heterogeneity rather than chance. Publication bias was evaluated using the Egger regression test.

RESULTS

The search in February 2023 revealed 909 records in PubMed. No additional articles were found in the Cochrane Library or PROSPERO. After excluding articles published before January 2010, 746 records remained, with no duplicates. After title screening, 632 records were excluded, with a further 84 excluded after abstract review. Full-text reading led to the exclusion of 18 additional records. Figure 1 illustrates the selection process adhering to the PRISMA 2020 guidelines.[24] Twelve articles published between 2010 and 2023[6–9,12,13,25–30] were identified (Table 1). The total CONSORT checklist scores ranged from 12.5 to 28.5 with a maximum possible score of 31. Abutment and crown types, considering implant connection, are detailed in Table 2. Table 3 compares cast-free digital, conventional, and hybrid workflows. The hybrid workflows were categorized into 4 groups: digital scanning with CAD-CAM casts, digital scanning with physical cast for ceramic veneering, conventional impression with casts digitized by laboratory scanner, and conventional impression with casts digitized by laboratory scanner using segmentation approach. Outcome variables are outlined in Table 4. Tables 5, 6, and 7 compare each stage of clinical and laboratory time. Cost analyses for clinical and laboratory steps in conventional, hybrid, and digital workflows are detailed in Table 8.

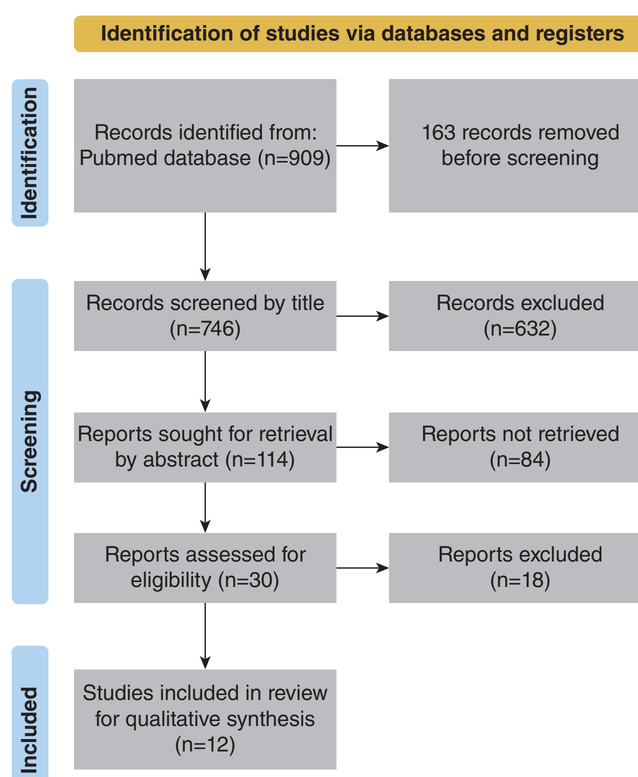

Figure 1. Flow chart for study inclusion.

Table 1. References included in qualitative synthesis

References	Titles	Sample Size	Design	Implant Connection
Joda and Bragger. 2015[25]	Time-efficiency analysis comparing digital and conventional workflows for implant crowns: a prospective clinical crossover trial.	20×2 implant-supported single units reconstructions in posterior sites (tissue level implants, Institute Straumann AG).	Crossover randomized controlled clinical trial	Cement connection
Joda and Bragger, 2014[26]	Digital vs. conventional implant prosthetic workflows: a cost/time analysis.	20×2 implant-supported single units reconstructions in posterior sites (tissue level implants, Institute Straumann AG).	Crossover randomized controlled clinical trial	Cement connection
Joda et al, 2015[27]	Clinical fitting and adjustment time for implant-supported crowns comparing digital and conventional workflows.	20×2 implant-supported single units reconstructions in posterior sites (tissue level implants, Institute Straumann AG).	Crossover randomized controlled clinical trial	Cement connection
Joda and Bragger, 2016[6]	Time-efficiency analysis of the treatment with monolithic implant crowns in a digital workflow: a randomized controlled trial.	10×2 implant-supported single units reconstructions in posterior sites (tissue level implants, Institute Straumann AG).	Parallel randomized controlled clinical trial	Screw connection
Mangano and Veronesi, 2018[13]	Digital versus analog procedures for the prosthetic restoration of single implants: a randomized controlled trial with 1 year of follow-up.	25×2 implant-supported single units reconstructions in posterior sites (single morse taper connection implant, Exacone, Leone implants).	Parallel randomized controlled clinical trial	Cement connection
Guo et al, 2019[28]	clinical efficiency and patient preference of immediate digital impression after implant placement for single implant-supported crown	20×2 impressions for implant-supported single units reconstructions in posterior sites (bone level implants, Institute Straumann AG).	Crossover controlled clinical trial	Not specified
Pan et al, 2019[7]	Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: a double-blind self-controlled clinical trial.	40×2 implant-supported single units reconstructions in posterior sites (Straumann Bone level, 1 piece and Straumann tissue level, 2 pieces).	Crossover double blinded randomized controlled clinical trial	Screw connection
Zhang et al, 2019[8]	Quantitative clinical adjustment analysis of posterior single implant crown in a chairside digital workflow: a randomized controlled trial.	33 implant-supported single units reconstructions in posterior sites (Camlog Screw Line, Camlog Biotechnologies AG).	Parallel randomized controlled clinical trial	Screw connection
Joda et al, 2021[29]	Time-efficiency and cost-analysis comparing three digital workflows for treatment with monolithic zirconia implant fixed dental prostheses: a double-blinded RCT.	20×3 3-unit implant fixed dental prostheses (iFDP) in posterior sites (tissue level implants, Institute Straumann AG)	Crossover double blinded randomized controlled clinical trial	Screw connection
Ren S, et al, 2022[12]	Crown accuracy and time efficiency of cement-retained implant-supported restorations in a complete digital workflow: a randomized control trial.	20×2 implant-supported single units reconstructions in posterior sites (Camlog Screw Line; Camlog Biotechnologies GmbH).	Randomized control clinical trial	Cement connection
Lee et al, 2022[30]	A clinical study comparing digital scanning and conventional impression making for implant-supported prostheses: a crossover clinical trial.	30×2 implant-supported single units reconstructions in posterior sites.	Crossover blinded randomized controlled clinical trial	Cement connection
Mühlemann et al, 2022[9]	Time efficiency and efficacy of a centralized computer-aided-design/computer-aided-manufacturing workflow for implant crown fabrication: a prospective controlled clinical study.	31 implant-supported single units reconstructions in posterior sites. (ASTRA TECH OsseoSpeed EV, Dentsply Sirona)	Parallel randomized controlled clinical trial	Screw connection

Table 2. Summary table of types of abutments and crowns reported in 12 studies included in systematic review

Implant Connection	References	Digital Workflows Without Physical Casts	Hybrid Workflows: Digital Scanning Technique and CAD-CAM Casts	Hybrid Workflows: Physical Cast Only For Ceramic Veneering	Hybrid Workflows: Cast Digitized With Laboratory Scanner	Hybrid Workflows: Cast Digitized with Laboratory Scanner (with and without Abutment)	Conventional Workflows
Cement-retained single crowns	Joda and Bragger, 2015[25] Joda and Bragger, 2014[26] Joda et al, 2015[27]			– CAD-CAM custom Ti abutments. – CAD-CAM custom ZrO_2 superstructure with ceramic veneering (Noritake CZR, Kuraray Noritake Dental Inc).			– Prefabricated Ti abutment (synOcta, Institute Straumann AG). – Porcelain fused to metal crown: metal coping (gold alloy PX Premium C, PX Dental) and ceramic veneering (Noritake EX3, Kuraray Noritake Dental Inc.).
	Mangano and Veronesi, 2018[13]	– Assembly of custom ZrO2 abutment by cementing upper ZrO2 portion on Ti base (Leone, Sesto). – CAD-CAM monolithic ZrO2 crown (Katana, Kuraray Noritake).					– Prefabricated Ti abutment. – Porcelain fused to metal crown: lost wax technique and ceramic veneering.
	Ren et al, 2022[12]	– CAD-CAM custom Ti abutment – CAD-CAM monolithic ZrO2 crown (Organical CAD-CAM GmbH).				– CAD-CAM custom Ti abutment. – CAD-CAM monolithic ZrO2 crown.	
	Lee et al, 2022[30]		– Prefabricated Ti abutment. – Monolithic LiSi2 crown (IPS e.max Press; Ivoclar AG).				– Prefabricated Ti abutment – Monolithic LiSi2 crown (IPS e.max Press; Ivoclar AG).
Screw-retained single crowns	Mühlemann et al, 2022[9]	– CAD-CAM custom Ti abutment (Atlantis, CustomBase solution, Dentsply Sirona). – CAD-CAM monolithic ZrO2 crown (Atlantis crown, complete contour, Dentsply Sirona) bonded on abutment.			– Prefabricated Ti base abutment (TitaniumBase EV, Dentsyply Sirona). – CAD-CAM monolithic ZrO2 crown bonded on abutment (Ceramill Zolid HT + preshades, Amann Girrbach AG).		
	Joda and Bragger, 2016[6]	– Prefabricated Ti base abutment (Variobase, Institute Straumann AG). – CAD-CAM monolithic LiSi2 crown bonded on abutment.		– CAD-CAM custom ZrO2 abutment (CARES, Institute Straumann AG). – CAD-CAM custom ZrO2 superstructure with ceramic veneering (Noritake CZR, Kuraray Noritake Dental Inc) bonded on abutment.			

Table 2 *(Continued)*

Implant Connection	References	Digital Workflows Without Physical Casts	Hybrid Workflows				Conventional Workflows
			Digital Scanning Technique and CAD-CAM Casts	Physical Cast Only For Ceramic Veneering	Cast Digitized With Laboratory Scanner	Cast Digitized with Laboratory Scanner (with and without Abutment)	
	Pan et al, 2019[7]	– Prefabricated Ti base abutment (Variobase, Institute Straumann AG). – CAD-CAM monolithic ZrO2 crown bonded on abutment.			– Prefabricated Ti base abutment (Variobase, Institute Straumann AG). – CAD-CAM monolithic ZrO2 crown bonded on abutment.		
	Zhang et al, 2019[8]	– Prefabricated Ti base abutment. – CAD-CAM monolithic LiSi2 crown bonded on abutment.			– Prefabricated Ti base abutment. – CAD-CAM monolithic ZrO2 crown bonded on abutment.		
Screw-retained on 3-unit iFDP	Joda et al, 2021[29]	– Prefabricated Ti abutment (Variobase, Institute Straumann AG). – CAD-CAM monolithic ZrO2 iFDP (VITA YZ ST, VITA Zahnfabric) bonded on abutment.			– Prefabricated Ti base abutment (Variobase, Institute Straumann AG). – CAD-CAM monolithic ZrO2 iFDP (VITA YZ ST, VITA Zahnfabric) bonded on abutment.		

CAD-CAM, computer-aided design and computer-aided manufacture; iFDP, implant fixed dental prosthesis; LiSi2, lithium disilicate; Ti, titanium; ZrO2, zirconia.

Table 3. Summary table of digital, conventional, and hybrid workflows reported in 12 studies included in systematic review

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows				Conventional Workflows
			Digital Scanning Technique and CAD-CAM Casts	Physical Cast Only for Ceramic Veneering	Casts Digitized with Laboratory Scanner	Casts Digitized with Laboratory Scanner (with and without Abutment)	
Cement-retained single crowns	Joda and Bragger, 2015[25] Joda and Bragger, 2014[26] Joda et al, 2015[27]			– Quadrant scan of implant site with scan body, opposing arch and occlusal registration (iTero Scanner, Align Tech Inc). – CAD-CAM for Ti abutment and ZrO2 coping (CARES X-Stream, Institute Straumann AG). – Milled definitive cast. – Ceramic veneering.			– Impression with polyether (Impregum, 3M Espe) and open tray. -Impression of opposing arch with alginate and occlusal registration. – Pouring definitive gypsum cast. – Using prefabricated Ti abutment in combination with manufacturing porcelain fused to metal framework – Ceramic veneering.
	Mangano and Veronesi, 2018[13]	– Quadrant scans of implant site without healing abutment and implant site with scan body, opposing arch and occlusal registration. – Design of upper portion of individual ZrO2 abutment (exocad DentalCAD, exocad). – Design of interim crown. – Milling of upper portion of custom abutment (Roland DWX-50, Roland Easy Shape) and sintering. – Milling, polishing and characterization of interim in PMMA. – Assembly of custom abutment by cementing extraorally upper ZrO2 portion on Ti base. – Delivery of interim crown. – Design, milling, and sintering of definitive ZrO2 crown.					– First impression with polyvinyl siloxane (Elite HDPlus, Zhermack) and close tray. – Impression of opposing arch with alginate and occlusal registration. – Pouring definitive gypsum cast. – Preparation of prefabricated Ti abutment. – Waxing for interim fabrication. – Lost-wax casting for metal coping fabrication. – Delivery of interim for temporization period of 2 months. – Second impression with polyvinyl siloxane (Elite HDPlus, Zhermack) and metal coping positioned on Ti abutment and retained in impression. – Pouring gypsum cast. – Stratify ceramic over metal structure of restoration.

Table 3 *(Continued)*

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows				Conventional Workflows
			Digital Scanning Technique and CAD-CAM Casts	Physical Cast Only for Ceramic Veneering	Casts Digitized with Laboratory Scanner	Casts Digitized with Laboratory Scanner (with and without Abutment)	
	Ren et al, 2022[12]	Split-file technique: design and manufacturing of custom abutment and crown simultaneously. – Complete arch scan of implant site with scan body, opposing arch and occlusal registration (TRIOS Color; 3Shape). – Crown designed from implant up and split into custom abutment and crown (Dental Designer, 3Shape). – Ti abutment manufactured using 5-axis milling machine (Organical Multi 5X, Organical CAD-CAM GmbH). – Crown manufactured using 5-axis milling machine (Organical Multi Changer 20; Organical CAD-CAM GmbH). – After milling and sintering, technician polished and refined milled abutment and crown to improve marginal fit.				Segmentation approach**:** – Impression with silicone and close-tray. – Impression of opposing arch with alginate and occlusal registration. – Implant casts poured and digitized with laboratory scan (TRIOS, 3Shape). – Custom Ti abutment designed using Dental Designer software program and milled using 5-axis milling machine (Organical Multi 5X). – Following adjustment and refinement, definitive casts digitized again. – Crown designed on abutment using Dental Designer software program. – ZrO2 crown fabricated using 5-axis milling machine (Organical Multi Changer 20) and refined by technician to improve marginal fit.	

Table 3 *(Continued)*

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows				Conventional Workflows
			Digital Scanning Technique and CAD-CAM Casts	Physical Cast Only for Ceramic Veneering	Casts Digitized with Laboratory Scanner	Casts Digitized with Laboratory Scanner (with and without Abutment)	
	Lee et al, 2022[30]		– Complete arch scan of implant site with scan body, opposing arch and occlusal registration (iTero Element; Align Technology Inc). – Data sent to custom milling center (Carlstadt; Align Technology Inc) for fabrication of CAD-CAM implant analog casts (Cadent iTero TM; Align Technology Inc). – Adjustment of pre-fabricated abutment – LiSi2 crown fabricated by waxing and pressing on cast.				– Impression with polyvinyl siloxane (Aquasil Ultra Monophase Light Viscosity; Dentsply Sirona) and close tray. – Impression of opposing arch with alginate and occlusal registration. – Pouring definitive gypsum cast with scannable Type IV gypsum (GC Fujirock EP OptiXscan; GC) and mounted on semi-adjustable articulator (Artex CR; Amann Girrbach AG). – Adjustment of prefabricated Ti abutment. – LiSi2 crown fabricated by waxing and pressing to prefabricated Ti abutment.
Screw-retained single crowns	Mühlemann et al, 2022[9]	– Complete arch scan of implant site with scan body, opposing arch and occlusal registration (TRIOS 3, 3Shape). – Digital scan data downloaded from cloud-based server (3Shape Communicate Portal) and uploaded to centralized server (Atlantis WebOrder, Dentsply Sirona). – Centralized CAD (Virtual Atlantis Design, Dentsply Sirona) with remote validation by dental technician and centralized CAM of abutment (Atlantis, CustomBase solution, Dentsply Sirona).			– Impression with polyether (Permadyne, 3 M) with open tray. – Impression of opposing arch with alginate and occlusal registration. – Implant cast poured and digitized with laboratory scan (Ceramill Map 400, Amann Girrbach AG). – CAD (Ceramill mind, Amann Girrbach AG) of ZrO2 crown on standardized Ti base abutment. – CAM (ceramill motion 2, Amann Girrbach AG) of ZrO2 crown. – Before sintering, crown adjusted on respective abutment/cast and internal staining applied.		

Table 3 *(Continued)*

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows: Digital Scanning Technique and CAD-CAM Casts	Hybrid Workflows: Physical Cast Only for Ceramic Veneering	Hybrid Workflows: Casts Digitized with Laboratory Scanner	Hybrid Workflows: Casts Digitized with Laboratory Scanner (with and without Abutment)	Conventional Workflows
		– ZrO2 crown shipped in sintered stage including custom Ti abutment.					
	Joda and Bragger, 2016[6]	– Quadrant scan of implant site with scan body, opposing arch and occlusal registration (iTero Scanner, Align Tech Inc). – Data sent to external center (CAD-CAM-Center, Institute Straumann AG) for milling. – LiSi2 crown bonded in laboratory to prefabricated Ti abutment.		– Quadrant scan of implant site with scan body, opposing arch and occlusal registration (iTero Scanner, Align Tech Inc). – Milled definitive cast – CAD-CAM processing ZrO2 abutment and ZrO2 coping (CARES X-Stream, Institute Straumann AG). – Milled definitive cast. – Ceramic veneering.			
	Pan et al, 2019[7]	– Complete arch scan, opposing arch and occlusal registration during initial exam (TRIOS 3, 3Shape) and partial scan immediately after implant placement with scan body. – Digital impression data transferred to CAD software program (3Shape Designer, 3Shape). – Full-contour crown designed on top of virtual Ti base. – CAM using laboratory-based milling machine (Zenotec Select Hybrid, Wieland Dental). – Milling and sintering. – ZrO2 crown bonded to Ti base abutment.			– Impression 3 months after implant placement, with polyether (Impregum Penta, 3 M ESPE GmbH) and close-tray. – Impression of opposing arch with alginate and occlusal registration. – Implant cast poured with stone type 5. – Scan body fixed on implant analog. – Digitizing casts with laboratory scanner (3Shape D 2000, 3Shape A/S). – Full-contour crown virtually designed on top of virtual Ti base. – CAM using laboratory-based milling machine (Zenotec Select Hybrid, Wieland Dental). – Milling and sintering of ZrO2-crown. – Adjust crown on cast.		

Table 3 *(Continued)*

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows: Digital Scanning Technique and CAD-CAM Casts	Hybrid Workflows: Physical Cast Only for Ceramic Veneering	Hybrid Workflows: Casts Digitized with Laboratory Scanner	Hybrid Workflows: Casts Digitized with Laboratory Scanner (with and without Abutment)	Conventional Workflows
	Zhang et al, 2019[8]	– Quadrant scan of implant site with scan body, opposing arch and occlusal registration (CEREC Omnicom, Sirona Dentsply). – Designing process (CEREC Omnicom, Sirona Dentsply). – File send to milling unit (CEREC MC XL Premium, Sirona Dentsply). – Through staining and crystallization, ceramic structure bonded on prefabricated Ti base abutment.			– Impression with silicone (Silagum, DMG) and closed-tray. – Implant casts poured and digitized with laboratory scan (TRIOS lab, 3Shape). – ZrO2 inner crown milled and sintered. – ZrO2 inner crown finalized with veneering and bonded on prefabricated Ti base abutment.		
Screw-retained on 3-unit iFDPs	Joda et al, 2021[29]	Test 1 – Complete arch scan of implant site with scan body, opposing arch and occlusal registration (TRIOS 3, 3Shape). – Files transferred to CAD software program (Dental System Lab-Software). Test 2 – Complete arch scan of implant site with scan body, opposing arch and occlusal registration (Dental Wings Virtuo Vivo). – Files transferred to CAD software program (DWOS Lab-Software). Test 1 and Test 2 – Design of iFDP based on automatic proposal of respective CAD software.			– Polyether Impression with open tray (Impregum, 3 M Espe) – Impression of opposing arch with alginate and occlusal registration. – Implant casts poured with stone type 4. – Digitizing casts with laboratory scanner (Ceramill Map 400+, Amann Girrbach AG). – CAD of iFDP (exocad Lab-Software, exocad). – ZrO2 iFDP milled with 5 axis unit (Ceramill 2 Motion, Amann Girrbach AG) and bonded on prefabricated Ti base abutment.		

Table 3 (*Continued*)

Implant Connection	References	Digital Workflows without Physical Casts	Hybrid Workflows				Conventional Workflows
			Digital Scanning Technique and CAD-CAM Casts	Physical Cast Only for Ceramic Veneering	Casts Digitized with Laboratory Scanner	Casts Digitized with Laboratory Scanner (with and without Abutment)	
		– ZrO2 iFDPs milled with 5 axis unit (Ceramill 2 Motion, Amann Girrbach AG) and bonded to prefabricated Ti base abutments.					
Type of single crowns not specified	Guo et al, 2019[28]	Immediate digital workflow Complete arch scan of implant site with scan body, opposing arch and occlusal registration (TRIOS Color, 3Shape A/S) directly after implant placement. Regular digital workflow Complete arch scan of implant site with scan body, opposing arch and occlusal registration (TRIOS Color, 3Shape A/S) 3 months after implant placement.					– Impression 3 months after implant placement with polyether (Impregum Penta, 3M ESPE GmbH) and close-tray. – Impression of opposing arch with alginate and occlusal registration.

CAD-CAM, computer-aided design and computer-aided manufacture; iFDP, implant fixed dental prosthesis; LiSi2, lithium disilicate; PMMA, polymethylmethacrylate; Ti, titanium; ZrO2, zirconia.

Table 4. Summary table of outcomes variables reported in 12 studies included in review

References	Time Efficiency	Cost Analyses
Joda and Bragger, 2015[25]	a. Clinical work time – Intraoral optical scans / impression making. – Placement of definitive crown. b. Laboratory work time	NE
Joda and Bragger, 2014[26]	NE	Direct treatment cost calculations in Swiss francs, according to Swiss dental association guidelines with standard tax-point value of 3.10 for dental fees – Direct clinical treatment cost. – Clinical material costs supplies/consumables. – Direct laboratory costs. – Clinical productivity rates.
Joda et al, 2015[27]	a. Clinical work time – Clinical adjustments for interproximal adaptations. – Clinical adjustments for occlusal modifications.	NE
Joda and Bragger, 2016[6]	a. Clinical work time – Intraoral optical scans. – Placement of definitive crown. b. Laboratory work time	Direct laboratory costs in Swiss francs (CHF) Dental fees were not assessed because no differences were applicable for test and control workflows according to Swiss dental association guidelines.
Mangano and Veronesi, 2018[13]	a. Clinical work time – Intraoral optical scans / impressions. – Delivery of interim restoration. – Delivery of definitive restoration. b. Laboratory work time – Production of interim crown. – Preparation of definitive restoration.	Expenses related to the purchase of materials and services of dental laboratory. Cost of treatment calculated in euros. – Materials. – Laboratory prices for production of interim crown. – Laboratory prices for production of definitive crown. Laboratory prices of mid-level laboratory located in northern Italy and VAT-exempted. Hourly cost of dental clinic not examined.
Guo et al, 2019[28]	a. Clinical work time – Immediate intraoral optical scans / complete arch scans / impression making	NE
Pan et al, 2019[7]	a. Clinical work time – Intraoral optical scan during initial exam and immediately after implant placement / impression making. – Crown delivery. b. Laboratory work time – Milling and sintering times excluded from analysis.	NE
Zhang et al, 2019[8]	a. Clinical work time – Intraoral optical scans / impression making. – Clinical adjustment of definitive crown. b. Laboratory work time – Total time and total active time.	NE
Joda et al, 2021[29]	a. Clinical work time – Intraoral optical scans / impression making. – Prosthetic delivery. b. Laboratory work time	Direct costs for technical production CHF – Consumed material and required working time. – Dental fees not assessed because no differences for the 3 workflows tested according to Swiss Dental Association guidelines.
Ren et al, 2022[12]	a. Clinical work time – Intraoral optical scans / impression making. – Crown adjustment. b. Laboratory work time – Milling and sintering times excluded from analysis.	NE
Lee et al, 2022[30]	Clinical work time – Preparation time. – Intraoral optical scan / impression making. – Time taken for remakes and rescans. – Adjustment time taken in delivering crowns.	NE
Mühlemann et al, 2022[9]	a. Clinical work time – Intraoral optical scans / impression making. b. Laboratory work time – Before implant crown ready for try-in. – Following clinical evaluation until delivery. – Total waiting time.	NE

CHF, Swiss francs; NE, not evaluated.

The time required for acquiring conventional impressions and digital scans was documented in 9 articles (Table 5).[7–9,12,13,25,28–30] Seven studies reported shorter scan times compared with conventional impressions.[7,9,13,25,28–30] One study reported no significant difference between digital and conventional techniques,[12] while another did not report statistical results.[8] Meta-analysis revealed that digital scanning was significantly more time-efficient compared with

Table 5. Time analyses of digital scans and conventional impressions steps for single implant crowns and iFDPs (minutes: seconds)

	Intraoral Optical Scans (Mean ±SD)						Conventional Impressions (Mean ±SD)	P
	ITero	**CS3600**	**TRIOS color**	**TRIOS 3**	**Cerec Omnicam**	**Virtuo Vivo**		
Joda and Bragger, 2015[25]	– Removal healing cap and insertion scan body. – Quadrant IOS, scan opposing arch and occlusal registration. – Removal scan body and insertion healing cap. – Color selection.						– Removal healing cap and insertion impression post – Open tray impression technique (implant site + adjacent teeth), impression of opposing arch, occlusal registration. – Removal impression post and insertion healing cap. – Color selection.	
	14:48 ±02:12						17:54 ±01:06	.001
Mangano and Veronesi, 2018[13]		– Healing Abutment removal. – IOS. – Color selection. – Healing Abutment re-insertion.					– Healing abutment removal. – Close tray impression technique. – Color selection. – Healing abutment re-insertion. – Resin crown removal. – Metal coping placement. – Second impression while metal coping positioned on abutment and retained in impression. – Resin crown re-cementation.	
		20:00 ±05:00					50:00 ±07:00	<.001
Guo et al, 2019[28]			– Insertion of scan body. – Complete arch scan directly after implant placement, scan of opposing arch and occlusal registration. – Removal of scan body. – Insertion of healing cap. – Color selection. 10:58 ±02:06[a] – Removal of healing cap. – Insertion of scan body.				– Tray selection. – Removal of healing cap. – Insertion impression post. – Open tray impression technique 3 months after implant placement (implant site and adjacent teeth), impression of opposing arch, and occlusal registration. – Removal of impression post. – Insertion of healing cap. – Color selection.	

Table 5 *(Continued)*

	Intraoral Optical Scans (Mean ±SD)						Conventional Impressions (Mean ±SD)	P
	ITero	CS3600	TRIOS color	TRIOS 3	Cerec Omnicam	Virtuo Vivo		
			– Complete arch IOS 3-months after implant placement, scan of opposing arch and occlusal registration. – Removal of scan body. – Insertion of healing cap. – Color selection. 10:13 ±02:42[a]				14:27 ±03:00[b]	<.050
Pan et al, 2019[7]				– Complete scan during initial exam of upper and lower arches + occlusal registration. – Connection of scan body. – Partial scan of scan body and teeth after implant placement. – Healing abutment connected to implant. 10:54 ±01:36			– Impression tray preparation. – Healing abutment removal. – Close tray impression technique 3 months after implant placement. – Impression of opposing arch. 14:18 ±02:54	<.001
Zhang et al, 2019[8]					Quadrant IOS, opposing arch, occlusal registration, cast obtained 14:48 ±02:12		Close tray impression technique. 08:18 ±0:30	NE
Ren et al, 2022[12]			Quadrant scan. 13:45 ±02:27				Close tray impression technique. 13:30 ±02:37	.757
Lee et al, 2022[30]	a- Preparation timeTime to enter participant's information into computer. b- Quadrant IOS – Scanning of scan body and remaining dentition. – Opposing arch. – Occlusal registration. c- Time taken for rescans 11:16 ±02:18						a- Preparation time Time elapsed for tray selection and application of tray adhesive. b- Impression making Working time measured from loading to complete setting of impression material at implant level (close tray impression technique) and opposing arch. c- Time taken for remakes 14:09 ±01:39	<.001

Table 5 *(Continued)*

	Intraoral Optical Scans (Mean ±SD)						Conventional Impressions (Mean ±SD)	P
	ITero	CS3600	TRIOS color	TRIOS 3	Cerec Omnicam	Virtuo Vivo		
Mühlemann et al, 2022[9]				– Healing abutment removal /fixation. – Scan body fixation/removal. – Complete arch scan with implant. – Scan for complete opposing arch and occlusal registration.			– Healing abutment removal / fixation. – Impression post fixation / removal. – Open tray impression of complete arch with implant. – Impression of complete opposing arch. – Occlusal registration.	
				09:30 ±03:30			15:06 ±04:36	<.001
Joda et al, 2021[29]				– Removal healing cap and insertion scan body. – Quadrant IOS for implant site + adjacent teeth, opposing arch and occlusal registration. – Removal scan body and insertion healing cap. – Color selection.		– Removal healing cap and insertion scan body. – Quadrant IOS for implant site and adjacent teeth, opposing arch and occlusal registration. – Removal scan body and insertion healing cap. – Color selection.	-Removal healing cap + insertion impression post.-Open tray impression technique for implant.-Alginate opposing arch.-Occlusal registration.-Removal impression post and insertion healing cap.-Color selection.	
				08:36 ±01:36[a]		17:18 ±03:36[c]	12:54 ±01:36[b]	<.001

a, b, c: indicate the presence of a significant difference between groups with post hoc tests.

IOS, intraoral optical scan.

conventional impressions (Hedges g=1.65, 95% CI [0.33, 2.98], P<.001). Heterogeneity among studies was substantial (Q statistic= 62.33, P<.001, I^2=90.37%). However, the Egger regression did not indicate publication bias (P=.136) (Fig. 2).

Table 6 displays the time analyses of digital, hybrid, and conventional laboratory steps for the fabrication of single crowns and 3-unit implant-supported fixed dental prostheses (iFDPs). For cement-retained implant crowns, Ren et al[12] reported significantly reduced dental laboratory technician working times with the cast-free digital workflow compared with the hybrid workflow (P<.001). Mangano et al[13] reported that the dental laboratory technician's active working time was more efficient in the cast-free digital workflow than in the conventional workflow for both interim and definitive crowns (P<.001). Joda et al[25] reported reduced laboratory work time in the hybrid workflow with a physical cast for ceramic veneering compared with the conventional workflow (P=.001).

Regarding screw-retained restorations, 5 studies found less active laboratory time in cast-free digital workflow compared with the cast-based hybrid workflow (P<.001) (Table 6).[6–9,29] Meta-analysis revealed a significant reduction in laboratory active working time with digital workflows compared with other methods, with a large effect size (Hedges g=6.55, 95% CI [2.69; 10.42], P<.001). Heterogeneity among studies was significant (Q statistic=120.37, P<.001, I^2= 96.68%). Also, potential publication bias was indicated by the Egger regression (P=.002) (Fig. 3).

In 5 of 9 studies, significant differences were observed in adjustment time among workflows. Two of the 3 studies found that conventional workflows required more time than hybrid workflows (P<.05).[25,27] Three of the 5 studies reported that hybrid workflows had significantly longer adjustment times compared with digital workflows (P<.05).[6,8,12] Furthermore, Mangano et al[13] reported no significant difference between conventional and digital workflows (p=0.500) (Table 7). Meta-analysis found no significant difference in adjustment time between digital and other workflows (Hedges g=0.91, 95% CI [−0.72; 2.55], P=.121). However, substantial heterogeneity among studies (Q statistic=53.45, P<.001, I^2=92.52%) and potential publication bias (Egger regression P=.039) were observed (Fig. 4).

Cost analyses for clinical and laboratory steps are presented in Table 8. Direct clinical treatment costs[6,26,29] and clinical material costs[13,26] did not reveal significant difference among workflows. However, direct laboratory cost was significantly higher in conventional workflows compared with hybrid[26] or digital workflows.[13] Moreover, direct laboratory costs were significantly elevated in hybrid workflows compared with digital workflows (Table 8).[6,29]

DISCUSSION

The null hypothesis that no difference would be found in time between IOSs and impression-making for the fabrication of implant-supported restorations was rejected. Among the 9 studies, 7 reported that IOSs required less time than impression-making.[7,9,13,25,28–30] The results of meta-analysis suggested a moderate to large effect size with considerable variability across studies, emphasizing the need for further investigation. The IOS technique is more straightforward to carry out but requires scan bodies and an IOS. The process of conventional impressions involves selecting and adjusting the tray, removing the healing abutment, inserting the impression post, and waiting for the impression material to polymerize. All clinical procedures must be repeated if the conventional impression needs to be retaken.[28] Conversely, with IOSs, the step-by-step scanning process allows for convenient modification and rescanning of specific dental sites.[31–34]

The null hypothesis that no difference would be found in laboratory time between workflows was also rejected. A substantial reduction in laboratory time favoring digital workflows over other methods, supported by a large effect size, was noted. All 8 studies evaluating laboratory time efficiency indicated that the time required for fabricating implant-supported restorations was shorter in digital workflows than in hybrid or conventional workflows.[6–9,12,13,29] Four studies reported that the fabrication of monolithic crowns was more rapid with digital workflows compared with hybrid or conventional workflows.[7,9,12,29] Moreover, laboratory time was shorter with hybrid than conventional workflows.[25] These findings can be attributed to reduced manual intervention and the elimination of manual fabrication steps in digital workflows. Cast fabrication can be omitted, and laboratory work steps may be simplified, ensuring standardized fabrication quality. However, the milling of implant prosthetic components and sintering of crowns may increase the overall laboratory working time with a digital workflow.[8,13]

Regarding adjustments, while 5 of the 9 studies[6,8,12,25,27] reported significant differences among workflows, the results of the meta-analysis did not show a significant difference. Computerized engineering

Table 6. Time analyses (hours: minutes: seconds) of digital, hybrid, and conventional laboratory working steps for single implant crowns and iFDPs

Mean ±SD		Digital workflows without Physical Casts	Hybrid Workflows: Physical Cast Only for Ceramic Veneering	Hybrid Workflows: Casts Digitized with Laboratory Scanner	Hybrid Workflows: Casts Digitized with Laboratory Scanner (with and without Abutment)	Conventional Workflows	P
Cement-retained single crowns	Joda and Bragger, 2015[25]		– CAD custom abutment. – CAD custom ZrO2-coping. – Preparation milled cast. – Ceramic veneering, glazing, and polishing.			– Preparation + mounting gypsum cast. – Selection of pre-fabricated abutment. – Manufacturing metal framework. – Ceramic veneering, glazing, and polishing.	
			02:38:06 ±00:17:12			03:09:48 ±00:25:18	.001
	Ren et al, 2022[12]	– CAD for abutment and crown. – Manual adjustment and polishing abutment and crown.			– Gypsum cast and cast scan. – CAD for abutment and crown. – Adjustment, polishing of abutment and crown.		
		00:43:42 ±00:05:33 *			01:24:33 ±00:05:48 *		<.001
	Mangano and Veronesi, 2018[13]	– CAD of individual abutment. – CAD of interim crown. – Milling, sintering of zirconia abutment. – Milling, polishing, characterization of PMMA crown. – Assembly of individual hybrid abutment.				– Preparation, polishing, and characterization of interim crown. – Preparation, polishing of metal coping.	
		01:10:00 ±00:15:00 *				05:40:00 ±00:37:00	<.001
		10:00:00 ±00:45:00				05:40:00 ±00:37:00	<.001
		– CAD of definitive zirconia crown. – Milling, sintering and characterization of zirconia crown.				– Preparation and polishing of definitive metal-ceramic crown.	
		00:20:00 ±00:09:00 *				04:20:00 ±00:26:00	<.001
		08:45:00 ±00:39:00				04:20:00 ±00:26:00	<.001
Screw-retained single crowns	Joda and Bragger, 2016[6]	– Virtual cast situation. – CAD of monolithic crown. – Bonding prefabricated abutment to LiS2 crown. – Polishing.	– Preparation of milled definitive cast. – CAD custom ZrO2 abutment. – Ceramic veneering, glazing, and polishing.				
		00:54:30 ±00:04:54	02:12:30 ±00:08:42				.001
	Pan et al, 2019[7]	– Data transfer to CAD. – CAD.		– Cast fabrication with implant analog with type 5 stone and cast scanning. – Data transfer to CAD-CAM. – Verification of crown on cast.			
		00:13:36 ±00:06:27 *		00:29:54 ±00:12:54 *			<.001
		– CAD monolithic LiSi2-crowns.					

Table 6 *(Continued)*

Mean ±SD		Digital workflows without Physical Casts	Hybrid Workflows: Physical Cast Only for Ceramic Veneering	Hybrid Workflows: Casts Digitized with Laboratory Scanner	Hybrid Workflows: Casts Digitized with Laboratory Scanner (with and without Abutment)	Conventional Workflows	P
	Zhang et al, 2019[8]	– CAM monolithic LiS2-crowns. – Bonding, staining, and crystallization.		– CAD-CAM zirconia inner crown. – Sintering zirconia inner crown. – Ceramic veneering. – Bonding, staining, and glazing.			
		01:30:30		11:04:12			<.001
		01:09:06 *		02:06:00 *			<.001
	Mühlemann et al, 2022[9]	Laboratory working time before crown was ready for try-in – Transfer of data. – Remote evaluation of crown design. – Assembly of components to be ready for try-in.		Laboratory working time before crown ready for try-in – Cast fabrication, mounting on articulator – Digitizing casts. – CAD-CAM of crown. – Assembly of components.			
		01:08:12 ±00:28:06 *		02:23:00 ±00:05:42 *			<.001
		Laboratory working time following clinical try-in until delivery – Application of external staining / glazing. – Cementation of crown onto abutment. – Polishing and cleaning.		Laboratory working time following clinical try-in until delivery – Staining, glazing, and bonding crown to abutment.			
		01:02:06 ±00:08:42 *		01:15:00 ±00:05:24 *			<.050
		Total waiting time – Shipping time.		Total waiting time – Cast fabrication/ mounting. -CAM: milling process.-Sintering of zirconia crown.			
Screw-retained iFDPs	Joda et al, 2021[29]	143:13:00 ±73:27:00 – Data processing: data download, matching, export, and nesting. – Fabrication: milling, sintering, adjustment, and finishing. – Corrections.		11:14:00 ±01:01:00 – Data processing: data download, matching, export, and nesting. – Fabrication: milling, sintering, adjustment, and finishing. – Corrections.			<.001
		01:24:00 ±00:14:30^a 02:50:00 ±00:24:48^c		02:35:00 ±00:26:48^b			<.001

* Active working time (no waiting time milling /sintering processes)

a, b, c: indicate the presence of a significant difference between groups with post hoc tests.

CAD-CAM, computer-aided design and computer-aided manufacture; iFDP, implant fixed dental prosthesis; LiSi2, lithium disilicate; PMMA, polymethylmethacrylate; ZrO2, zirconia.

Table 7. Time analyses (minutes: seconds) for clinical adjustment and delivery of single implant crowns and iFDPs in digital, hybrid, and conventional workflows

Mean ±SD		Time Analyses For Clinical Adjustments Steps	Digital Workflows Without Physical Casts	Hybrid Workflows				Conventional Workflows	P
				Digital Scanning and CAD-CAM Casts	Physical Cast only for Ceramic Veneering	Casts Digitized With Laboratory Scanner	Casts Digitized with Laboratory Scanner (With and Without Abutment)		
Cement-retained single crowns	Joda and Bragger, 2015[25]	Removal healing cap Insertion of zirconia crown • Placement of abutment • Interproximal adjustment • Internal and marginal fit Cementation Periapical radiograph			12:30 ±02:42			15:18 ±04:36	.010
	Joda et al, 2015[27]	Interproximal adjustment Occlusal adjustment Total time			01:00 ±01:12 01:12 ±01:18 02:12 ±02:06			03:12 ±03:18 02:48 ±01:24 06:00 ±03:54	.006 .002 <.001
	Mangano and Veronesi, 2018[13]	− Delivery of interim restoration Healing abutment removal Insertion and activation of abutment Delivery / cementation of interim crown	11:00 ±5:00					09:00 ±04:00	.500
		- Delivery of definitive restoration Removal of interim crown Placement, adjustment, and cementation	14:00 ±5:00					12:00 ±5:00	.500
	Ren et al, 2022[12]	Occlusal adjustment Interproximal adjustment	06:27 ±02:12				13:09 ±03:50		<.001
	Lee et al, 2022[30]	Interproximal adjustment Internal and marginal fit Occlusal adjustment		03:46				04:21	.940
Trans-occlusal screw-retained single crowns	Joda and Bragger, 2016[6]	Removal healing cap Insertion of LiS2-crown / adjustment: • Interproximal contacts • Occlusal plane Screw placement and closure access hole Periapical radiograph	07:24 ±00:12		10:30 ±01:42				.001
	Pan et al, 2019[7]	Interproximal adjustment Occlusal adjustment	12:18 ±02:54			11:24 ±02:35			.256
	Zhang et al, 2019[8]	Removal of healing cap Insertion of definitive crown Adjustment Screw retention and closure	08:24 ±03:30			12:18 ±03:42			.007
Trans-occlusal screw-retained iFDPs	Joda et al, 2021[29]	Removal healing cap Try-in monolithic ZrO2 iFDP • Interproximal adjustment • Occlusal adjustment • Pontic area adjustment Color check Screw retention + closure access holes	TRIOS3 + Dental System Lab-Software program 04:54 ±02:42 Virtuo Vovo + DWOS Lab-software program 05:48 ±02:54			04:42 ±02:42			.320

CAD-CAM, computer-aided design and computer-aided manufacture; iFDP, implant fixed dental prosthesis; LiSi2, lithium disilicate; ZrO2, zirconia.

Table 8. Cost analyses of clinical and laboratory steps for 12 studies included in systematic review

		Cost Analyses	Digital Workflows without Physical Casts	Hybrid Workflows: Physical Cast only for Ceramic Veneering	Hybrid Workflows: Physical Cast only for Ceramic Veneering	Conventional Workflows	P
Cement-retained single crowns	Joda and Bragger, 2014[26]	Direct clinical treatment cost		– Initial examination. – Implant crown. – Color selection. – Occlusal registration. – Assembly of auxiliary components. – Intraoral radiograph. 809.10 CHF		– Initial examination. – Implant crown. – Color selection. – Occlusal registration. – Assembly of auxiliary components. – Intraoral radiograph. 809.10 CHF	
		Clinical material costs supplies / consumables		– Implant scan body. – Scansleeve (iTero). – Scanfee (iTero). 64.30 CHF		– Impression post. – Impression material (Impregum). 65.00 CHF	>.050
		Direct laboratory costs		– Milled cast (iTero). – Implant analog (iTero). – Implant supra-structure CAD-CAM. – Straumann CARES titanium abutment cem. – Straumann CARES zirconia coping. – Ceramic veneering. – Material ceramic veneering. – Individual characterization/unit. – Work time in units/hour. 941.95 CHF		– Gypsum definitive cast. – Implant analog. – Peri-mucosal mask. – Gypsum cast for opposing arch. – Mounting articulator and cast analysis. – Straumann synOcta titanium abutment cem. – Straumann synOcta plastic cap crown. – 3 g PX Premium S (gold alloy). – Casting crown frame. – Ceramic veneering and material ceramic veneering. – Individual characterization/unit. – Work time in units/hour. 1245.65 CHF	.003
		Overall treatment direct costs		1815.35 CHF		2119.65 CHF	.004
		Clinical productivity rate		Dentist's prosthetic profit rate for 1 implant crown extrapolated to 1 h. By dividing clinical fee (809.10 CHF) by estimated mean clinical treatment time (27.3 min). 29.64 CHF/min; 1778.24 CHF/hour		Dentist's prosthetic profit rate for 1 implant crown extrapolated to 1 h. By dividing clinical fee (809.10 CHF) by estimated mean clinical treatment time (33.2 min). 24.37 CHF/min; 1462.23 CHF/hour	.002; cost reduction of 18%
	Mangano and Veronesi, 2018[13]	Direct laboratory costs	Materials: scan body and abutment. 107.3 Euros Laboratory for production of interim resin crown and hybrid abutment. 60 Euros Laboratory for production of definitive zirconia crown and characterization. 110 Euros Total: 277.3 Euros			Materials: impression post, abutment, and implant analog. 107.2 Euros Laboratory for production of interim resin crown and abutment preparation. 75 Euros Laboratory for production of definitive metal-ceramic crown. 210 Euros Total: 392.2 Euros	

Table 8 *(Continued)*

		Cost Analyses	Digital Workflows without Physical Casts	Hybrid Workflows		Conventional Workflows	P
				Physical Cast only for Ceramic Veneering	Physical Cast only for Ceramic Veneering		
Screw-retained single crowns	Joda and Bragger, 2016[6]	Direct laboratory costs	Laboratory fees for first line production in CHF. 505.85 CHF		Laboratory fees for first line production in CHF. 748.75 CHF		<.001
Screw-retained iFDPs	Joda et al, 2021[29]	Direct laboratory costs	Consumed material and required working time. 566 ±49.3 CHF for TRIOS 3 + Dental System Lab Software program711 ±78.8 CHF for Virtuo Vivo + DWOS Lab-Software program		Consumed material and required working time. 812 ±89.6 CHF		<.001

CAD-CAM, computer-aided design and computer-aided manufacture; CHF, Swiss Francs; iFDP, implant fixed dental prosthesis.

technology offers advantages such as high precision, streamlined fabrication procedures, and reduced manpower requirements, mainly due to the elimination of several manual fabrication steps in digital workflows.[35] However, skilled operators in digital, hybrid, and conventional workflows may achieve similar outcomes in terms of clinical adjustment, ensuring that adjustments are minimal, regardless of the fabrication method.

The null hypothesis that no difference would be found in cost between IOSs and impression-making for fabricating implant-supported restorations was also rejected. Studies indicated that conventionally or hybrid-manufactured implant crowns were more costly throughout the clinical and laboratory process compared with digitally fabricated restorations[13,26] and that hybrid workflows had higher costs than digital workflows.[6,29] The purchase of equipment is an additional cost consideration. The digital workflow requires the purchase of an IOS, along with subsequent software program updates and maintenance costs. In contrast, conventional impression making requires trays, impression materials, and mixing machines. In this context, comparing the costs of digital and conventional equipment is more complex because both IOSs and conventional impressions are routinely used for fixed and removable prostheses.[26] The studies included in the review did not include an overall cost separation.

The authors are unaware of previous systematic reviews that compared the time efficiency and cost-effectiveness of conventional, hybrid, and digital workflows in fabricating implant-supported prostheses. All the included studies were randomized clinical trials, which helped minimize confounding factors during comparisons. However, limitations included the focus on the fabrication of implant-supported single crowns and 3-unit iFDPs, omitting long-span implant-supported prostheses. Secondly, inconsistencies were observed in the timing analyzed and the fabrication steps of restorations, emphasizing the lack of standardized conventional, hybrid, or digital workflows techniques. The significant heterogeneity observed among studies may be attributed to variations in study designs, sample populations, and methodologies. Factors such as differences in operator experience, type of digital equipment used, and patient characteristics could also have influenced times. Further research is warranted to understand the difference in time efficiency between workflows. Thirdly, while 6 digital systems (iTero, CS3600, TRIOS Color, TRIOS 3, Cerec Omnicam, and Virtuo Vivo) were assessed, other available digital systems were not addressed. Finally, the scope of the cost analysis was limited to selected countries, potentially overlooking variations in dental care reimbursement systems across different regions.

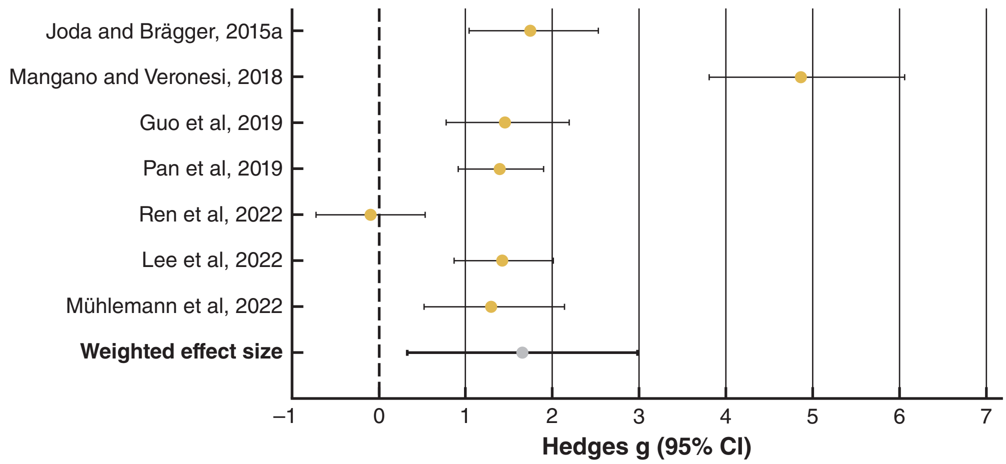

Figure 2. Forest plot illustrating effect size with 95% confidence interval depicting difference in impression time between digital and conventional workflows.

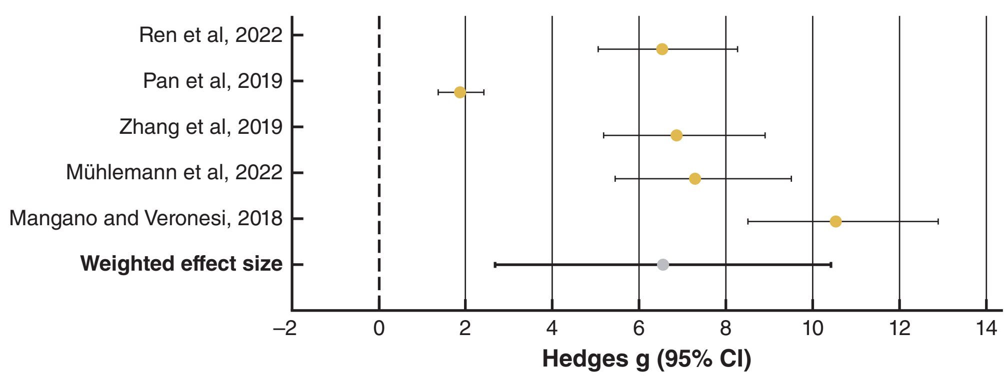

Figure 3. Forest plot illustrating effect size with 95% confidence interval depicting difference in laboratory active working time between digital workflows versus other workflows.

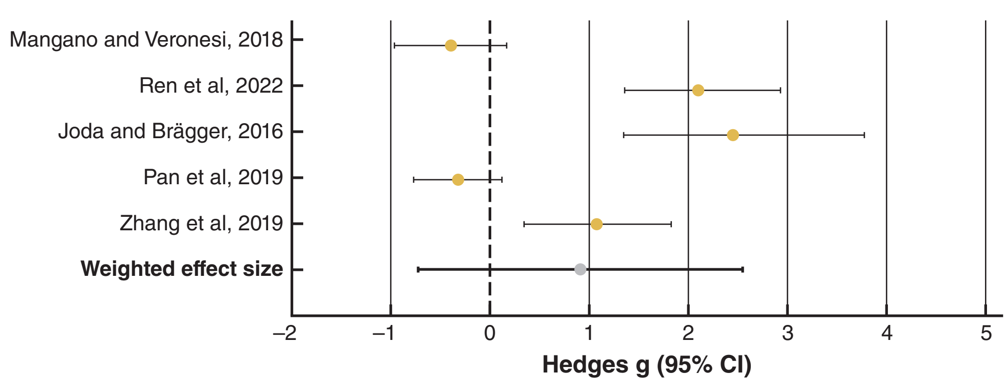

Figure 4. Forest plot illustrating effect size with 95% confidence interval depicting difference in adjustment time between digital workflows versus other workflows.

CONCLUSIONS

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

1. The digital workflow outperformed both the hybrid and conventional pathways in terms of time efficiency in manufacturing implant-supported prostheses.
2. Impression and laboratory working time were shorter with the digital compared with the hybrid workflow, which in turn exhibited shorter durations than the conventional pathway.
3. For 3-unit iFDPs, variations in clinical and laboratory times were observed, depending upon the digital system used for IOSs and CAD-CAM.

Moreover, fabricating an implant-supported single-unit restoration or a 3-unit iFDP incurred higher expenses with the conventional workflow, intermediate costs with the hybrid workflow, and lower costs with the digital workflow.

4. These findings remain inconclusive, as further evaluation of time efficiency across multiple digital systems and cost analyses in various countries with differing dental care reimbursement systems are imperative. Further clinical studies are also needed to investigate the efficiency for long-span implant-supported fixed prostheses.

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