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SYSTEMATIC REVIEW

Which clinical and laboratory procedures should be used to fabricate digital complete dentures? A systematic review

Khaing Myat Thu, BDS, DipDSc, PhD,[a] Pedro Molinero-Mourelle, Dr med dent, PhD,[b] Andy Wai Kan Yeung, BDS, PhD,[c] Samir Abou-Ayash, Prof, Dr med dent,[d] and Walter Yu Hang Lam, BDS, MDS(Pros), AdvDipProsth, FHKAM, FCDSHK, MFDS (RCSEd), MFDS (RCPSG), FDS (RCSEd), FDS (RCPSG), MPros RCSEd, FRACDS[e]

ABSTRACT

Statement of problem. Digital workflows for digital complete denture fabrication have a variety of clinical and laboratory procedures, but their outcomes and associated complications are currently unknown.

Purpose. The purpose of this systematic review was to evaluate the clinical and laboratory procedures for digital complete dentures, their outcomes, and associated complications.

Material and methods. Electronic literature searches were conducted on PubMed/Medline, Embase, and Web of Science for studies published from January 2000 to September 2022 and screened by 2 independent reviewers. Information on digital complete denture procedures, materials, their outcomes, and associated complications was extracted.

Results. Of 266 screened studies, 39 studies were included. While 26 assessed definitive complete dentures, 7 studies assessed denture bases, 2 assessed trial dentures, and 4 assessed the digital images only. Twenty-four studies used border molded impression technique, 3 studies used a facebow record, and 7 studies used gothic arch tracing. Only 13 studies performed trial denture placement. Twenty-one studies used milling, and 17 studies used 3D printing for denture fabrication. One study reported that the retention of maxillary denture bases fabricated from a border-molded impression (14.5 to 16.1 N) was statistically higher than the retention of those fabricated from intraoral scanning (6.2 to 6.6 N). The maximum occlusal force of digital complete denture wearers was similar across different fabrication procedures. When compared with the conventional workflow, digital complete dentures required statistically shorter clinical time with 205 to 233 minutes saved. Up to 37.5% of participants reported loss of retention and up to 31.3% required a denture remake. In general, ≥1 extra visit and 1 to 4 unscheduled follow-up visits were needed. The outcomes for patient satisfaction and oral health-related quality of life were similar between conventional, milled, and 3D-printed complete dentures.

Conclusions. Making a border-molded impression is still preferred for better retention, and trial denture placement is still recommended to optimize the fabrication of definitive digital complete dentures. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Computer-aided design and computer-aided manufacturing (CAD-CAM) system for complete denture fabrication has greatly advanced, offering benefits such as fewer clinical visits with shorter chairtime,[1-3] better material properties,[4] and cost savings.[2,5,6] Digital denture technology began as early as 1994,[7] with earlier techniques[7-9] making edentulous impressions before the intraoral scanning of edentulous jaws was proposed.[10] Most earlier digital dentures followed conventional denture techniques, but gradually a fully digital workflow was adopted.[11,12] Furthermore, the recent development of materials and technology has made 3D printing a suitable option for digital dentures.[13]

The digital workflow for the fabrication of complete

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[a]Senior Research Assistant, Restorative Dental Sciences, Faculty of Dentistry, The University of Hong Kong, Hong Kong Special Adminstrative Region, PR China.
[b]Research Assistant, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine University of Bern, Bern, Switzerland.
[c]Tutor in Oral and Maxillofacial Radiology, Applied Oral Sciences and Community Dental Care, Faculty of Dentistry, The University of Hong Kong, Hong Kong Special Adminstrative Region, PR China.
[d]Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland.
[e]Clinical Assistant Professor in Prosthodontics, Restorative Dental Sciences, Faculty of Dentistry, The University of Hong Kong, Hong Kong Special Adminstrative Region, PR China.

Clinical Implications

Extra clinical visits may be needed to address the problems of retention, jaw relationship errors, and poor esthetics of digital complete dentures, emphasizing the need for making an optimal impression, recording correct jaw relationships, and trial denture placement.

dentures has been evaluated in clinical studies, in which time and costs,[2,5,6] clinical outcomes,[3,13,14] patient-reported outcomes,[13-17] and denture complications[18-20] have been investigated. Although some of these studies reported favorable results and edentulous patients may have benefited by attending fewer clinical visits than with conventional dentures,[1] complications with digital complete dentures such as extra visits and clinical time for adjustment, repair, or even remake have been reported.[16,18-21]

Edentulous jaws can be captured by making an impression or intraoral scanning, and denture bases can be fabricated by milling or 3D printing. The outcomes,[22] associated complications,[21] or both[4,23] of digital complete dentures have been evaluated.[24] However, reviews of denture fabrication procedures and their outcomes or associated complications are lacking. Therefore, this systematic review aimed to evaluate clinical and laboratory procedures for fabricating digital complete dentures, their outcomes, and associated complications among published clinical studies. The research hypothesis was that the outcomes and complications of digital complete dentures would be associated with their clinical and laboratory fabrication procedures.

MATERIAL AND METHODS

This systematic review was conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 expanded format[25] and was registered on the PROSPERO International prospective register of systematic reviews (CRD42023393061). The review question "What outcomes or complications are associated with various clinical and laboratory procedures for the fabrication of digital complete dentures in previous clinical studies?" was designed by using a population, intervention, control, and outcomes (PICO) model: completely edentulous population, digital complete dentures intervention, conventional denture workflow as control, and all outcomes including complications associated with digital complete dentures. Two independent assessors (K.M.T., P.M.-M.) searched electronic literature related to digital complete dentures on PubMed/Medline, Embase, and Web of Science databases from January 2000 to September 2022. Supplementary hand-searching on Google Scholar and tracing references of selected studies was used to identify any missing studies. Search terms and search queries are presented in Supplementary Table 1 (available online).

The retrieved studies were first screened according to the relevance of titles and abstracts. The shortlisted studies were then assessed with full-text analysis in which the inclusion criteria were: clinical studies only, written in English, using subjective or objective measurements to assess the outcomes or associated complications. Studies written in other languages, those not related to clinical study, and studies other than original research articles such as case reports, short communications, commentaries, and reviews were excluded. Disagreements between assessors were resolved by discussion. The risk of bias in each study was assessed by an independent and calibrated assessor (K.M.T.). The screening process and data extraction were performed using a systematic review software program (Covidence; Veritas Health Innovation).

The data were extracted by the same assessors independently, and any differences were resolved through discussion. Extracted data from each study include details of the clinical and laboratory procedures of digital complete denture fabrication, number of dentures or specimens and denture materials, outcomes, associated complications, and maintenance needs. The frequency of use of each clinical and laboratory procedure and the complications were recorded. Evaluation of these data was categorized into clinical procedures, laboratory procedures and denture materials, and outcomes and associated complications.

RESULTS

A total of 1780 studies were screened for the relevance of title and abstract after the removal of duplicates. The shortlisted 266 studies were assessed for full text, and 39 studies (Table 1) were included for data extraction according to the eligibility criteria (Fig. 1). The assessment results for risk of bias for different study designs are presented in Supplementary Tables 2 to 4, available online. Seven randomized controlled trials[13,26-31] had fair to good quality, but 13 cohort studies[1-3,20,32-40] and 3 other studies[16,41,42] were considered poor quality. The remaining studies were also considered fair to good quality.

Among 39 included studies, 7 studies[33,37,38,40,43-45] assessed denture bases, 2 studies[8,36] assessed trial dentures, and 26 studies[1-3,5,6,13-20,26-31,41,42,46-50] investigated definitive complete dentures, including 2 studies[26,29] with implant overdentures (IOD). Four studies[32,34,35,39] assessed digital scans of impression or edentulous jaws for

Table 1. Clinical studies with digital denture fabrication or digital analysis included[1,2,3,5,6,8,13–20,26–50]

No.	Study	Study objects (or) Examined specimens	No. of digital dentures	Digital systems	Visits	Primary impression making	Definitive impression making	Digitization of edentulous arch	Jaws relationship record	Use of articulator mounting	Trial placement	Clinical remount	Fabrication of definitive complete dentures	Denture occlusal scheme	Materials used for denture base	Maintenance needs before denture delivery	Follow-up or complaints
1	**Inokoshi 2012**[8]	Wax CD	10	3D CAD software program (CATIA V5R19, Dassault Systems, France; & FreeForm, SensAble Technologies, USA)	NA	by duplicate denture	By wash impression without border molding (using duplicate denture)	Scanned the manually fabricated wax denture (conventional wax trial dentures)	Using duplicate denture	Mechanical articulator (Brand: Not specified)	Wax denture	NA	Only 3D-printed trial dentures	Not specified	Ultraviolet-polymerized acrylic-based resin material (FullCure 720, Objet Geometries)	-Needed for teeth rearrangement -Needed to re-fabricate	3D-printed dentures showed inferior stability
2	**Katase 2013**[41]	CD Set	10 (Same as above study)	Mimis CAD software program	-	NA	NA	NA	Using old denture	Not specified	NA	NA	3D Printing	Not specified	Ultraviolet-polymerized acrylic-based resin material	NA	NA
3	**Kattadiyil 2015**[14]	CD Set	15	Avadent	2	NA	Border-molded impression	Not specified	Avadent protocol	NA	NA	NA	Milling	Lingualized occlusion	Not specified	-Anterior open occlusal relationship occurred -need to re-fabricate	6.6% of patients (anterior open relation)
4	**Saponaro 2016**[16]	CDs	50	Avadent	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not specified	NA	NA	NA
5	**Saponaro 2016**[42]	CDs	48 (Same as above study)	Avadent	2	NA	NA	NA	NA	NA	NA	NA	NA	Not specified	NA	22/90 - got CD at 3rd appointment 4/22 - incorrect occlusal vertical dimension 3/22 - incorrect CR	0.39 extra visits 2.08 recall visits 31.25% repair 37.5% lab reline 12.5% soft reline 6.25% fracture 33% required 1 adjustment visit 29% requiring 2 adjustment visits 8/22 - lack of denture retention 3/22 - unacceptable esthetics 1/22- reported altered speech
6	**Schwindling 2016**[3]	CD Set	20	Wieland Dental Digital Denture system	4	polyvinyl siloxane monophase	Border-molded impression (with milled custom tray)	Scanned the impression	Ivoclar centric tray, occlusal plane & gothic arch tracing	Wieland system teeth arrangement (no virtual articulator)	Wax denture with acrylic resin base	Not specified	Injection mold vs. Milling	Not specified	PMMA disks (IvoBase CAD for Zenotec; Wieland Dental)	2 cases – insufficient OVD after preliminary JRR 1 case - excessive lip support 1 case –small buccal corridor 2 cases - teeth reposition -Corrections for esthetic problems: shifted midlines, deviated from interpupillary line or Camper plane	20% mandibular CD - loss of retention 2 out of 5 patients have occlusal error ≥2 out of 5 patients have esthetic problem

Table 1 *(Continued)*

7	**Bidra 2016**[17]	CD Set/ CD & IOD	40	Global Dental Science	2	No	Border-molded impression (with duplicate denture)	Scanned the impression	Duplicate denture (trimmed and added wax as necessary)	Virtual tooth arrangement	No Trial	NA	Milling	Lingualized occlusion	Prepolymerized acrylic resin block	1-loss of retention 3-excessive wear of teeth 1-need for significant number of adjustments 2- required additional appointment	NA
8	**AlHelal 2016**[43]	Maxillary denture base	20	Avadent	2	Alginate	Border-molded impression (with 3D-printed custom tray)	Scanned the impression	No jaw registration	NA	No trial (denture base only)	NA	Conventional heat-activated polymerization vs. milling	NA	Not specified	NA	NA
9	**AlRumaih 2018**[44]	Maxillary denture base	20 (same as above study)	Avadent	2	Alginate	Border-molded impression (with 3D-printed custom tray)	Scanned the impression	No jaw registration	NA	No trial (denture base only)	NA	Conventional heat-activated polymerization vs. milling	NA	Not specified	NA	NA
10	**Schlenz 2018**[19]	CD Set	20	Ivoclar AG	4	Not specified	Ivoclar protocol	Not specified	Schwindling's protocol (using Ivoclar centric tray, occlusal plane & gothic arch tracing)	Wieland system teeth arrangement (no virtual articulator)	Wax denture with acrylic resin base	NA	Milling	Not specified	NA	NA	0.6 extra visit 1.7 recall visit in first 4 weeks 2.07 for after 4 weeks 66.7% pressure sore 22.2% have loss of retention
11	**Drago 2019**[18]	CD Set	73	Avadent	4	Preliminary border molding	Border-molded impression	Scanned the impression	Using occlusion rims over relined impression trays	NA	Milled trial denture	Clinical & Laboratory remount in Trial stage	Milling	Not specified	Not specified	NA	NA
12	**Cristache 2019**[46]	CDs	45	3Shape	3	Alginate	Border-molded impression	Not specified	Conventional JRR with occlusion rim on custom tray	Virtual articulator mount in 3Shape	NA	NA	DLP 3D printing	Not specified	0.4% TiO2-nanoparticle-reinforced PMMA composite resin	NA	-3.06 denture adjustments (unscheduled visits) -2 dentures- accidentally broken and reprinted -Reduction in retention and stability occurred after 18 months
13	**Srinivasan 2019**[5]	Maxillary CDs/ CD set	12	Avadent	2	NA	Master impression without border molding	Scanned the impression	Avadent Anatomical Device & gothic Arch Tracing	virtual record model and teeth setup	NA	NA	Conventional vs. Milling	Not specified	Not specified	Chairside time is longer than the previous studies (undergraduate operators)	NA
14	**Smith 2020**[2]	CD Set	30	Ivoclar AG	4	Performed (not specified technique)	Border-molded impression	Not specified	Ivoclar centric tray, occlusal plane & gothic arch tracing (as Schwindling 2016)	NA	3D-printed trial denture	NA	Milling	Not specified	NA	NA	NA
15	**Lo Russo 2020**[32]	Digital Images (impression and IOS)	-	TRIOS	-	NA	Conventional impression (with 3D-printed custom tray but not specified about border molding) vs. Intraoral scan	Intraoral scanning	-	NA	NA	NA	NA	NA	No definitive complete dentures	NA	NA
16	**Yoon 2020**[37]	Denture bases + occlusion rims	-	3Shape	4	Alginate	Border-molded impression	Scanned the stone cast	Conventional JRR with occlusion rim on 3D-printed baseplate	NA	NA	NA	Conventional heat-activated polymerization vs. milling vs. DLP	NA	-PMMA block (VIPI Block GUM) -DLP printable resin (NextDent Base; Next-Dent B.V.)	NA	NA
17	**Cristache 2020**[15]	CD Set (same with above)	45	exocad	2 or 3	Alginate	Border-molded impression	Scanned the impression	Gothic arch tracing using Candulor instrument set & occlusal plane indicator, facebow	Using Artex®CR virtual articulator (exocad GmbH, Germany) CAD software program	NA	NA	DLP 3D printing	Not specified	0.4% TiO2-nanoparticle-reinforced PMMA composite resin	NA	4.4% fracture

Table 1 (*Continued*)

18	**Arakawa 2021**[6]	CD Set	16	Avadent and Wieland	Avadent -2, Wieland -4	Not specified	Border-molded impression	Not specified	NA	NA	NA	NA	Milling vs. Conventional heat-activated polymerization	Not specified	NA	NA	NA
19	**Peroz 2021**[28]	CD Set	16	Baltic Denture System	2	NA	Border-molded impression	Scanned the impression	Using BD keys	Not specified	NA	NA	Milling	Canine guidance	Not specified	NA	NA
20	**Stein 2021**[34]	Digital Images (impressions)	-	Scanned image only	-	Alginate	Border-molded impression	Scanned the impression	No jaw registration	NA	NA	NA	NA	NA	NA	NA	NA
21	**Lo Russo 2021**[33]	Maxillary denture base	-	3Shape	3	NA	Intraoral scan	Intraoral scanning	NA	NA	NA	NA	Milling vs. 3D printing	NA	-Milling- PMMA blanks of (Ruthinium DISC pink; Dental Manufacturing S.P.A.) -3D printable resin (NextDent Denture 3D+; NextDent B.V.)	NA	NA
22	**Srinivasan 2021**[13]	CD set		Avadent	6	Alginate	Border-molded impression	Scanned wax denture	Gothic arch tracing and facebow record	Mechanical semi-adjustable articulator	Wax dentures try-in with teeth selection	NA	Milling vs. 3D printing	Bilateral balanced occlusion	Not specified	NA	3D-printed CD - three maintenance visits (planned visit: n=1, unscheduled visit: n=2)
23	**Chaturvedi 2021**[47]	CD Set	45	Meshmixer software program- version 3.5, Autodesk, Inc., USA	Not specified	Performed (not specified specifically)	Border-molded impression	Scanned the stone cast	Using facebow and interocclusal record but not specified using with either occlusion rim or denture	Mechanical semi-adjustable articulator (Not-specified)	NA	NA	conventional vs. milled vs. 3D printing	Bilateral balanced vs. Linualized vs. Monoplane occlusion	- Milling: Polymerized, monomer-free PMMA blank (Vipi Block Gum CAD/CAM Blank, Dark Pink, Veined) - Formlabs Denture Base Resin, Dentca Inc.	NA	NA
24	**Deng 2021**[48]	CD Set	80	Hoteamsoft Co. Ltd., Jinan, China	3	Impression compound	Border-molded impression (with 3D printed Diagnostic denture)	Scanned the impression	Primary JRR - using silicone in 1st impression Definitive JRR - by diagnostic dentures	Not specified	3D-printed diagnostic denture	NA	Conventional heat-activated polymerization	Not specified	No digital denture produced	NA	1- visit was added for trial denture 1- facial midline was inconsistent with the lip midline.
25	**Elawady 2021**[26]	Maxillary CD & Mandibular IOD	14	3Shape	not clear	Performed (not specified specifically)	Conventional impression (not specified about border molding)	Scanned the bite record and master cast	Conventional JRR with occlusion rim	Mechanical articulator (Not specified: just report as conventional denture)	NA	NA	DLP 3D printing	Bilateral balanced occlusion	pink denture base printing resin (NextDent, Denture 3+)	NA	NA
26	**Faty 2021**[45]	Maxillary denture base	-	3Shape	-	Alginate	Border-molded impression	Scanned the stone cast	NA	NA	NA	NA	CAD-CAM vs. Conventional heat-activated polymerization	NA	-Milling: Pink prepolymerized PMMA (Glorious Dental Materials) -3D Printing : pink denture base printing resin (NextDentBase)	NA	NA
27	**Clark 2021**[1]	CDs	39	Avadent	4	Performed (not specified specifically)	performed	Not specified	Not specified	Not specified	Wanger Try-in	Not specified	Milling	Not specified	Not specified	NA	12.8% need remakes or repairs
28	**Kim 2021**[20]	CDs	216	Dentca denturebase 2	~5	Alginate	Border-molded impression	Scanned the mounted stone cast on articulator	Using occlusion rim	Using mechanical semi-adjustable articulator (Hanau)	3D-printed trial denture	NA	3D printing	Not specified	Dentca Denture base II (printing resin) and teeth resins (Dentca Inc., Torrance, CA)	NA	>20% CD- ≥3 times recall >28% CD - remake or repair 35% pressure sore, 22 % has retention problem. 3.2% occlusion problem, 9.25% esthetic problem.
29	**El Galil 2021**[50]	CD Set	40	3Shape vs. exocad	maybe 4	Alginate	Conventional impression (not specified about border molding)	Scanned master cast	Using occlusion rim	Not specified	NA	NA	3D printing	Not specified	Pink denture base printing resin (NextDent, Denture 3+)	NA	NA

Table 1 *(Continued)*

30	**Li 2022**[36]	Test 3D printed Denture	12	Hoteamsoft Co. Ltd	-	Impression compound	Silicone impression with diagnostic denture (not specified about border molding)	scanned the impression-loaded diagnostic denture	Primary JRR - using silicone material in first impression Definitive JRR - by diagnostic dentures	Not specified	NA	NA	3D Printing	Bilateral balanced occlusion	Not specified	NA	NA
31	**Ohara 2022**[27]	CD Set	40	Not specified	3	NA	Border-molded impression (with Dentca trays)	Scanned the impression	Gothic arch tracing using definitive impression-loaded trays	Not specified	3D-printed trial denture	NA	3D printing	Not specified	Trial Denture: Dima denture base try-in; Kulzer Japan Co., Ltd.	Remake was reported but not specified clearly	Number of adjustments & time for fabrication & adjustment – same as conventional CD
32	**Otake 2022**[49]	CD Set	88	3Shape	3	NA	performed (using 3D-printed trial dentures)	Scanned the impression	Primary JRR - using silicone material in first impression Definitive JRR - by trial dentures	NA	3D-printed trial denture	Not specified	Milling	Not specified	Custom-made resin disk	NA	NA
33	**Aboheikal 2022**[30]	Maxillary CDs	48	exocad	Not specified	Not specified	Not specified	Scanned the stone cast	Using occlusion rim	Mechanical articulator (Bio Art A7 Dental Equipment)	3D-printed trial denture	Not specified	Conventional heat-activated polymerization vs milled vs 3D printing	Not specified	-Denture base printing resin (NextDent, Denture 3+) -PMMA blank (Dental CAD-CAM blank, WIESSEN)	NA	NA
34	**El-Shaheed 2022**[29]	Mandibular IODs	10	exocad	Not specified	Performed (not specified specifically)	Border-molded impression	Scanned the stone cast	Using occlusion rim	Not specified	No trials	Not specified	Conventional heat-activated polymerization vs milled	Bilateral balanced occlusion	gingival-colored prepolymerized PMMA blocks (PMMA Disc, bio HPP)	NA	NA
35	**Naggar 2022**[31]	Maxillary CDs	32	Not specified	Not specified	Not specified	performed	Scanned the stone cast	Using occlusion rim	Not specified	No trials	Not specified	Conventional heat-activated polymerization vs 3D printing	Not specified	NextDent denture base printing resin	NA	NA
36	**Li 2022**[35]	Digital Images (JRR of arches with the scan of impressions)	-	Hoteamsoft Co. Ltd	3	Impression compound	Border-molded impression (with 3D printed diagnostic denture)	Scanned the impression	Primary JRR - using silicone material in first impression Definitive JRR - by diagnostic dentures	Not specified	3D-printed trial denture	NA	Conventional heat-activated polymerization	NA	NA		
37	**Al Hamad 2022**[39]	Digital Images (arch)	-	Not specified	NA	Impression compound	Border-molded impression vs. Intraoral scan	Scanned the stone cast vs. Intraoral scanning	NA	NA	NA	NA	NA	NA	NA	NA	NA
38	**Maniewicz 2022**[40]	Maxillary denture base	-	Avadent	4	Alginate	Border-molded impression (with 3D printed trays)	Scanned the stone cast	NA	NA	NA	NA	conventional vs. milled vs. 3D printing	NA	Denture base printing resin (NextDent; Vertex-Dental BV) AvaDent Denture Base Puck; Global Dental Science Europe BV	NA	NA
39	**Chebib 2022**[38]	Maxillary denture base	-	Avadent	4	Alginate	Border-molded impression (with 3D printed trays) vs. Intraoral scan	Scanned the stone cast vs. Intraoral scanning	NA	NA	NA	NA	Milling and 3D printing	NA	Denture base printing resin (NextDent; Vertex-Dental BV) AvaDent Denture Base Puck; Global Dental Science Europe BV	NA	NA

CAD, computer-aided design; CD, complete denture; DLP, digital light processing; IOD, implant overdenture; JRR, jaws relationship recording; NA, not accessible; Not specified, performed procedure but not reported clearly.

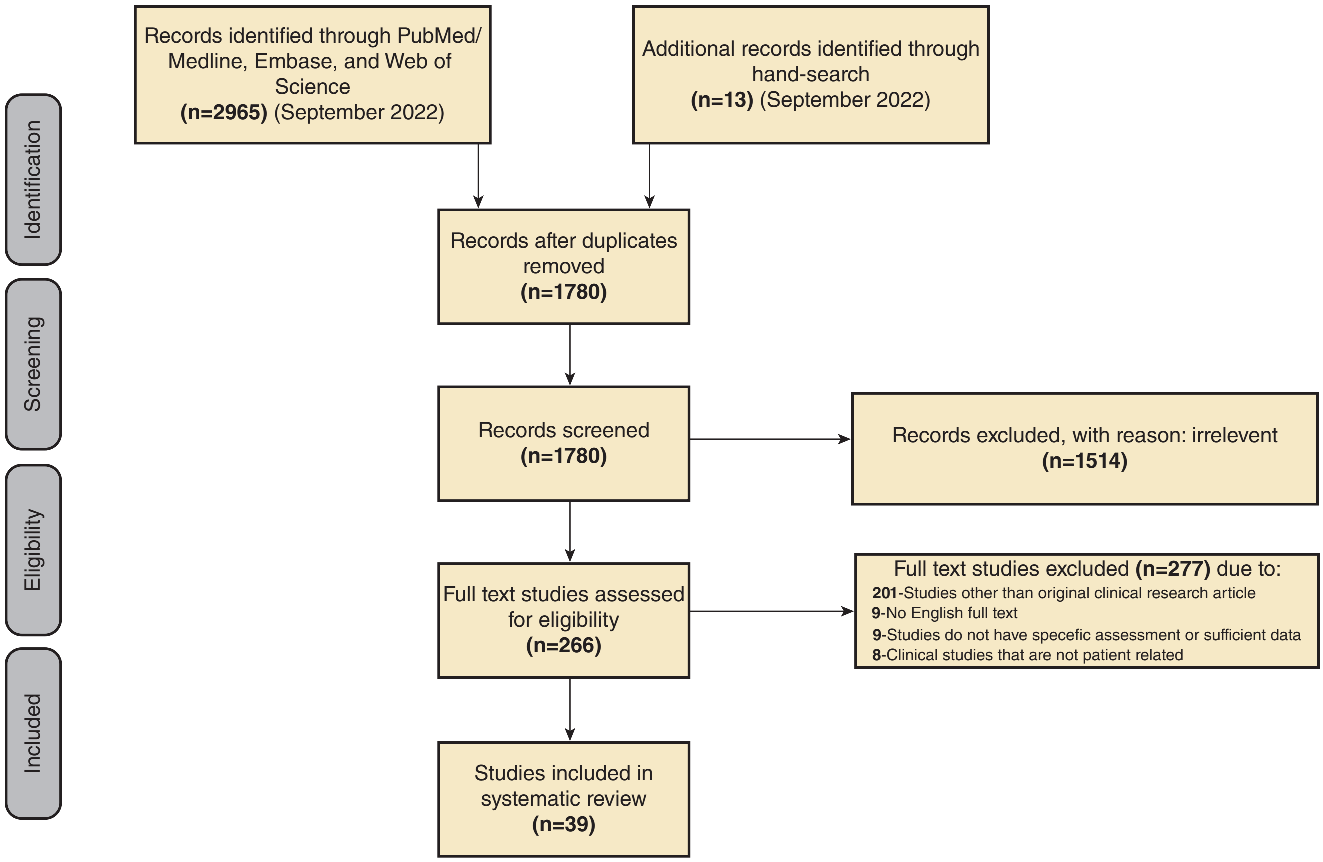

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart for screening of studies by inclusion and exclusion criteria.

trueness and/or accuracy. For studies assessing IODs,[26,29] 1 study compared oral health-related quality of life (OHRQoL) between conventional and 3D-printed IOD.[26] Another study investigated occlusal force and tissue surface adaptation.[29] For studies that assessed denture bases, 5 studies[38,40,43-45] assessed retention, and 2 assessed accuracy.[33,37] Details of each included study are presented in Table 1.

Thirty-four studies[1-3,5,6,8,13-15,17-20,26-29,31,32,34-40,43-50] used the conventional impression technique, and 24[2,3,6,13-15,17,18,20,27-29,34,35,37-40,43-48] of them also adopted border molded impression technique. Among studies using the conventional impression technique, 5 studies[3,38,40,43,44] used CAD-CAM fabricated custom trays after primary impression making (1 milled and four 3D-printed), and 1 study[32] produced 3D-printed custom trays after intraoral scanning. Four studies[35,36,48,49] used 3D-printed diagnostic or trial dentures as the custom trays. Fourteen studies[3,5,15,17,18,27,28,34-36,43,44,48,49] scanned the impression to digitize the edentulous jaws, 12 studies[20,26,29-31,37-40,45,47,50] scanned the stone casts, and 2 studies[8,13] scanned the conventional wax trial dentures. An intraoral scanner was used to scan the edentulous jaws in 4 studies,[32,33,38,39] but dentures were not fabricated in these studies.

In 9 studies,[18,20,26,29-31,37,46,50] the maxillomandibular jaw relationship was recorded by using occlusion rims, and 7 studies[8,17,35,36,41,48,49] used existing dentures, diagnostic dentures, or their duplicates. Three studies specified the facebow record,[13,15,47] and 7 studies used gothic arch tracing.[2,3,5,13,15,19,27] Several commercially available digital jaw relationship record systems were found: 3 studies used the Ivoclar system (Ivoclar AG),[2,3,19] 2 studies used the AvaDent system (Global Dental Science LLC),[5,14] and 1 study used Baltic Denture Key system (Merz Dental GmbH).[28] For the Ivoclar and AvaDent systems, jaw relationship may be recorded in 2 stages. The preliminary jaw relationship was recorded with putty followed by the definitive jaw relationship recorded with trial dentures or custom trays, which might be evaluated before the definitive complete dentures are produced.[35,36,48,49]

Six studies[8,13,20,26,30,47] used mechanical articulators, while 2 virtual articulators, 3Shape (3Shape A/S) and exocad (exocad GmbH), were used in 2 studies.[15,46] Four studies[3,5,17,19] reported virtual tooth arrangement but without specifying the virtual articulator. Other studies did not report the articulator system used. Regarding the occlusal scheme of digital complete dentures, 4 studies[13,26,29,36] used bilateral balanced occlusion, 2 studies[14,17] used lingualized occlusion, 1 study[28] used canine guidance, and 1 study[47] compared 3 occlusal schemes - bilateral balanced, lingualized, and monoplane occlusions. Only 13 studies[1-3,8,13,18-20,27,30,35,48,49] reported trial placement in the digital workflow, in which 7 studies[2,20,27,30,35,48,49] used 3D-printed and 1 study[18] used milled trial dentures. Only 1 study[18] reported a remount procedure.

Among the 11 CAD software programs reported, AvaDent (Global Dental Science LLC) was the most commonly used software program (12 studies[1,5,6,13,14,16,18,38,40,42-44]) followed by 3Shape (3Shape A/S) (7 studies[26,33,37,45,46,49,50]), exocad (exocad GmbH) (4 studies[15,29,30,50]), Ivoclar system (Ivoclar AG) (2 studies[2,19]), and Wieland (Wieland Dental) (2 studies[3,6]). Twenty-one studies[1-3,5,6,13,14,17-19,28-30,33,37,38,40,43,44,47,49] milled and 17 studies[8,13,15,20,26,27,30,31,33,36-38,40,41,46,47,50] 3D-printed the definitive complete dentures, denture bases, or trial dentures. Milling denture base materials were mainly polymethyl methacrylate (PMMA) (11 studies[3,17,29,30,33,37,38,40,45,47,49]), while 3D printing used acrylic-based resins, including printable denture resin (12 studies[20,26,27,30,31,33,37,38,40,45,47,50]), ultraviolet (UV) polymerized acrylic resin (2 studies[8,41]), and titanium dioxide nanoparticle-reinforced PMMA composite resin (2 studies[15,46]) (Table 1).

The accuracy of impression methods for digital complete dentures is summarized in Table 2. Maxillary denture bases showed the maximum discrepancy to the actual tissue surfaces (0.6 to 0.7 mm), which was measured using the thickness of the fit-checking materials.[37] The mean discrepancies between denture bases and stone casts or intraoral scanning or digital images of the dentures were all below 0.5 mm.[8,29,33,38,40,50] The mean discrepancy between intraoral scanning and the conventional impression was less than 0.2 mm, while that to the stone cast was less than 0.9 mm.[32,34,38,39,48]

A summary of the retention of digital complete dentures is listed in Table 3. The retentive force was measured in vivo with a digital force gauge in 5 studies,[26,30,43-45] a dynamometer in 2 studies,[38,40] and a universal testing machine in 1 study.[31] Digital complete dentures showed better retention than conventional complete dentures.[31,40] Most digital complete dentures have a mean retentive force of 13 to 20 N. The highest retentive force was up to 74 N among maxillary denture bases fabricated from border-molded impressions, while denture bases fabricated from intraoral scanning had the least retentive force of approximately 6 N. One study reported that the retention of maxillary denture bases fabricated from a border-molded impression (14.5 to 16.1 N) was statistically higher than those fabricated from intraoral scanning (6.2 to 6.6 N).[38] The retention of maxillary denture bases fabricated from a scan of definitive impressions[43,44] was not statistically different from those fabricated from a scan of stone casts poured from definitive impressions.[45] Clinicians scored the maxillary complete dentures fabricated by milling as having better retention than that using the injection-mold technique.[3] Only 2 studies[13,14] measured denture stability subjectively, and both found that the stability of digital complete dentures was satisfactory.

The maximum occlusal force was measured in vivo using T-scan in 1 study[47] and using an occlusal force meter in 2 studies.[13,29] Maximum occlusal force was reported from 130 to 225 N for digital complete dentures[13,29,47] and was similar across different fabrication procedures (Table 3).

Patients required fewer clinical visits for the fabrication of digital complete dentures than for conventional complete dentures. The preliminary impression-making and trial placement visits may be skipped, resulting in 2 to 4 fewer visits (Table 4). When compared with a conventional workflow, a reduction in clinical time (58 to 233 minutes) was specified in the fabrication of digital complete dentures than in the fabrication of conventional complete dentures.[2,5,6,14,27,28] Digital complete dentures required statistically shorter clinical time, with 205 to 233 minutes saved in 2 studies.[5,14] Laboratory time was reduced up to 5 hours.[28]

In addition to the recommended number of visits, extra visits may be needed to adjust digital complete dentures (Table 5). The mean number of recall visits for postoperative review or denture adjustments were 1.0 to 4.0.[1,13,15,18-20,27,42,48] The complications and extra visits needed are summarized in Table 5. Denture repairs or remakes were up to 31.3% of participants in 1 study.[42] Complications with retention were found in 20.0% to 37.5% of prostheses, while other complications such as jaw relationship errors, esthetic complications, and prostheses fractures were found in less than 10.0% of prostheses.[3,14,17-20,42] The scores of patient satisfaction and OHRQoL were similar among conventional, milled, and 3D-printed complete dentures (Table 3).

DISCUSSION

Since the fabrication of digital complete dentures is relatively new, additional well-controlled clinical trials are needed to investigate the outcomes of individual procedures. This review, however, summarized the current evidence of the digital complete denture procedures and provided updated information. The research hypothesis of an association between the clinical procedures and outcomes or complications was mainly supported.

Most included studies adopted the border-molded impression technique. While intraoral scanning with border trimming has been proposed for edentulous impressions,[32,38] the fabrication of digital complete dentures based on intraoral scanning was not common. The retention of maxillary denture bases fabricated from border-molded impressions was statistically higher than

Table 2. Clinical studies on accuracy of denture or impression and reported maximum mean values

Outcomes	Study	Comparison	Systems or Software Programs	Fabrication	Study Objects and Comparisons	Mean or Maximum Inaccuracies
Surface adaptation or Fitness or Accuracy of denture bases	Inokoshi 2012[8]	Wax denture vs 3D-printed trial denture	3DCAD (CATIA)	3D printing	Maxillary CD Mandibular CD	0.0051 mm 0.023 mm
	Yoon 2020[37]	Fabrication methods vs actual tissue surface of jaws (by thickness of indicator)	3Shape A/S	Milling	Maxillary denture base Mandibular denture base	0.44-0.701 mm 0.16-0.35 mm
				DLP 3D printing	Maxillary denture base Mandibular denture base	0.31-0.59 mm 0.17-0.32 mm
				Conventional heat-activated polymerization	Maxillary denture base Mandibular denture base	0.29-0.61 mm 0.27-0.36 mm
	Lo Russo 2021[33]	Fabrications vs Digital image of the corresponding designed denture base	3Shape A/S	3D printing	Maxillary denture base (overall accuracy)	0.002 mm
				Milling	Maxillary denture base (overall accuracy)	0.018 mm
	El Galil 2021[50]	CAD software program (definitive CD vs scanned stone cast)	3Shape vs exocad	3D printing	3 Shape exocad	0.09 mm 0.25 mm
	El-Shaheed 2022[29]	Fabrications (Stone scan vs IOD base)	exocad	Milling Conventional heat-activated polymerization	Mandibular IOD base (+/-) Mandibular IOD base (+/-)	0.034/-0.055 mm 0.099/-0.081 mm
	Maniewicz 2022[40]	Fabrications (Stone scan vs denture base)	Avadent	Conventional heat-activated polymerization	Maxillary denture base	0.18 mm
				3D printing Milling	Maxillary denture base Maxillary denture base	0.20-0.23 mm 0.21-0.23 mm
	Chebib 2022[38]	Milled vs 3D-printed denture bases vs Intraoral scan	Avadent	3D printing Milling	Maxillary denture base Maxillary denture base	0.21-0.22 mm 0.21 mm
Trueness or Accuracy of impression or Intraoral scanner or Digitized models	Lo Russo 2020[32]	Maxillary and mandibular conventional impression vs IOS	Not used	NA	Full scan Trimmed scan	-0.19 mm 0.02 mm
	Stein 2021[34]	Selective pressure impression by various relief trays vs Control (No relief tray conventional border-molded impression) at anterior ridge and median palatal suture	Not used	NA	Control difference (both no relieves) 1 mm relief tray vs no relief 3 mm relief tray vs no relief	0.07 mm 0.03 mm 0.04 mm
	Deng 2021[48]	Impression vs Denture base	Hoteamsoft Co Ltd	Conventional heat-activated polymerization	Maxillary denture base vs impression	0.165 mm
	Al Hamad 2022[39]	Stone cast scan vs Intraoral scanner	Not specified	NA	Maxillary Mandibular	-0.57 to 0.45 mm -0.85 to 0.85 mm
	Chebib 2022[38]	Intraoral scanner vs Stone cast	Avadent		Intraoral scanner vs stone cast (root mean square)	0.45 mm

CD, complete denture; DLP, digital light processing; IOD, implant overdenture.

Table 3. Clinical outcomes and patient-reported outcomes of digital complete dentures

Outcomes Measured	Study	Specimens or Study Objects	Definitive Complete Dentures Fabrication Methods	Outcomes Reported			
Objective retentive force measurements	AlHelal 2016[43]	Maxillary denture base	Conventional heat-activated polymerization vs milling		Conventional CD base	Milled CD base	
	AlRumaih 2018[44]			Retention (N)	54.2	74.1	
	Faty 2021[45]	Maxillary denture base	Conventional heat-activated polymerization vs milling vs 3D printing		Conventional CD base	Milled CD base	3D-printed CD base
				Retention (N)	67	73	68
	Elawady 2021[26]	Maxillary CD and Mandibular IOD	Conventional heat-activated polymerization vs 3D printing	Retention (N)	Conventional CD base	3D-printed CD base	
				Baseline	10.7	14.4	
				3 mo	9.9	13.6	
				6 mo	8.9	12	
				12 mo	7	10.3	
	Aboheikal 2022[30]	Maxillary CD	Conventional heat-activated polymerization vs milling vs 3D printing	Retention (N)	Conventional CD	Milled CD	3D-printed CD
				Baseline	~15	~13	17.2
				3 mo	~18	~18	19.6
				6 mo	~22	~20	22.6
	Naggar 2022[31]	Maxillary CD	Conventional heat-activated polymerization vs 3D-printing	Retention (N)	Conventional CD	3D-printed CD	
				Baseline	11.3	19.8	
				1 mo	9.8	18.6	
				3 mo	8.5	17.9	
				6 mo	7.3	15.8	
				9 mo	4.3	12.6	
	Maniewicz 2022[40]	Maxillary denture base	Conventional heat-activated polymerization vs milling vs 3D printing		Conventional CD base	Milled CD base	3D-printed CD base
				Retention (N)	10.5	13.4	14.1
	Chebib 2022[38]	Maxillary denture base	Conventional border-molded impression vs intraoral scanner	Retention (N)	Milled CD base	3D-printed CD base	
				Conventional IOS	14.56.6	16.16.2	
Subjective measurements of denture retention and stability	Kattadiyil 2015[14]	Maxillary and Mandibular CD set	Conventional heat-activated polymerization vs milling	1. Higher ratings for retention and stability by clinicians 2. Significantly higher rating for retention in maxillary arch			
	Schwindling 2016[3]	Maxillary and Mandibular CD set	Milling injection molding	Retention of maxillary prostheses was rated slightly better for milled CDs			
	Bidra 2016[17]	Maxillary and Mandibular CD set Or CD and IOD set	Milling	(100 mm VAS, baseline → 1 y) 91.5 → 79.3 (by clinicians) 86.2 → 84.5 (by patients)			
	Cristache 2019[46]	CD (any)	Old denture vs 3D printing		Old denture	3D-printed maxillary CD	3D-printed mandibular CD
				Modified Kapur Index (MKI)	≤3	7 (5-9)	4 (3-5)
	Srinivasan 2021[13]	CD set	Milling 3D printing		Milled CD	3D-printed CD	
				Retention (patient' score)	3.80-4.73/5	3.40-4.27/5	
				Stability (patient' score)	3.93-4.67/5	3.75-4.47/5	
				Retention (Dentist' counting dentures)	29/30	26/30	
				Stability (Dentist' counting dentures)	30/30	30/30	

Table 3 (*Continued*)

Outcomes Measured	Study	Specimens or Study Objects	Definitive Complete Dentures Fabrication Methods	Outcomes Reported			
Masticatory performance (maximum occlusal force and chewing efficiency)	Chaturvedi 2021[47]	5 patients	Conventional heat-activated polymerization vs milling vs 3D printing	Maximum occlusal force %	Conventional CD	Milled CD	3D-printed CD
				Bilateral balance occlusion	~90	~91	~92
				Lingualized occlusion	~94	~95	95.4
				Monoplane occlusion	~81	~85	~87
	Srinivasan 2021[13]	15 patients	Milling vs 3D-printing		Milled CD	3D-printed CD	
				Maximum occlusal force (N)	154.7	131.2	
				Mastication efficiency (Variance of Hue)	0.3	0.4	
				Mastication efficiency (Subjective)	2.9	2.7	
	El-Shaheed 2022[29]	10 patients	Conventional heat-activated polymerization vs milling	Maximum occlusal force (N)	Milled IOD	Conventional IOD	
				3 mo	208	166	
				6 mo	225	170	
PROs (patient satisfaction OHRQoL and assessments)	Inokoshi 2012[8]	10 patients	3D printing (Trial dentures)	- No difference - esthetics, predictability of definitive complete dentures shape, stability, comfort of dentures, or overall satisfaction			
	Kattadiyil 2015[14]	15 patients	Milling	- Significantly higher patient scores for the digital CD - No significant preference on esthetics - Higher preference for digital CD for comfort, chewing efficiency, prostheses, and efficiency of the technique			
	Saponaro 2016[16]	50 patients	Not specified	- 78.9% - pleased with the esthetics of digital CD - 78.6% - new digital CDs were "better" - 73.7% - satisfied with their new CDs - 68.8% - new CDs were easy to clean - 68.4% - "comfortable" and recommend to others - 57.9% - speech and chewing abilities had improved - 52.6% - fit well and stable - But no significant difference from conventional			
	Bidra 2016[17]	20 patients	Milling	79% satisfied with CAD-CAM dentures ~50% did not rate good or excellent for retention, stability, and adaptation of the bases			
	Cristache 2020[15]	35 patients	DLP 3D printing	OHIP EDENT	3D-printed CD		
				Baseline	52.6		
				12 mo	20.7		
				18 mo	20.4		
	Peroz 2021[28]	16 patients	Conventional heat-activated polymerization vs milling	OHIP G49	Conventional	Digital	
				Baseline	0.3	2.7	
				14 d	5.3	8.1	
				3 mo	11.3	5.4	
	Elawady 2021[26]	28 patients	Conventional heat-activated polymerization vs DLP 3D printing	OHIP	Conventional CD	3D-printed CD	
				Baseline	55.9	54.8	
				6 mo	49.2	39.1	
				12 mo	42.8	31.4	
	Srinivasan 2021[13]	15 patients	Milling vs 3D printing		Milling	3D-printed CD	
				OHIP score	16.7	26.9	
				Patient satisfaction maxillary CD	4.5	4.1	
				Patient satisfaction mandibular CD	4	3.5	
				8 patients preferred milling while 7 preferred 3D-printed dentures.			

Table 3 *(Continued)*

Outcomes Measured	Study	Specimens or Study Objects	Definitive Complete Dentures Fabrication Methods	Outcomes Reported
	Ohara 2022[2]	20 patients	3D printing	- VAS and OHIP scores not significantly different. - VAS satisfaction ~80 to 90 for conventional CD, ~70 for digital CD - CDs >DDs for phonetics, ease of cleaning, stability, comfort, and general satisfaction
	Otake 2022[4]	44 patients	Conventional heat-activated polymerization vs milling	VAS satisfaction 84.0 mm for digital CD and 91.0 mm for conventional CD.
	Aboheikal 2022[30]	48 patients	Conventional heat-activated polymerization vs milling vs 3D printing	Least satisfaction found in milled groups followed by conventional, while highest satisfaction found in 3D-printed group.
	Maniewicz 2022[40]	20 patients	Conventional heat-activated polymerization vs milling vs 3D printing (denture bases only)	Patients score favorably on VAS satisfaction for all CDs. Surface smoothness scored more favorably on conventional CD than on other CDs.

CD, complete denture; DLP, digital light processing; IOD, implant overdenture; OHIP, oral health impact profile; OHRQoL, oral health-related quality of life; PROs, patient reported outcomes; VAS, visual analog scale.

that of those fabricated from an intraoral scan.[38] Moreover, both denture wearers and clinicians rated the retention of digital complete dentures fabricated from border-molded impressions to be satisfactory.[3,14,17] The mucocompressive nature of conventional impression-making may be responsible for the close tissue adaption and resulting improved retention.[32] For intraoral scanning, the largest deviation typically occurred at the mobile mucosa,[39] including the soft palate, sublingual areas, and vestibule,[51] important locations for the peripheral seal and retention. Furthermore, denture stability was investigated in only 2 studies by using subjective assessment.[13,14] More studies are needed to objectively assess denture stability.

Conventional record bases with occlusion rims, existing dentures, or their duplicates, were commonly used to record the jaw relationship during digital denture fabrication.[20,26,29-31,50] Sometimes jaw registration and definitive impression-making were performed at the same visit.[3,15,17-19,27,36,46,48,49] In some commercially available systems, jaw relationship was recorded in 2 stages, which may allow trial placement of dentures in the second stage.

While gothic arch tracing has been specified as a standard method for recording jaw relationships in digital complete denture workflows,[3,19] the clinical superiority of using a facebow, gothic arch tracing, and articulator in the fabrication of digital complete dentures remains unclear from this review. Occlusal relationship errors such as the improper vertical dimension of jaws and the anterior open occlusal relationship were commonly reported. These errors might be associated with imprecise jaw relationship records and a lack of trial denture placement and clinical remount steps.[14,42] Only 13 studies performed trial denture placement, while most studies omitted this step.

Poor esthetics was a common complication,[3,20,42] with problems that included deviated dental midlines, excessive gingival display,[42] and unsatisfactory denture tooth and denture base shade.[1] Occlusal errors were also common. Additional visits were needed for corrections or even remaking digital dentures.[1,3,19,42] Trial denture placement allows correction of these errors and obtaining patient approval of the esthetics. Evaluation of the digital preview of the dentures on a computer screen was found to be more difficult than a wax denture intraorally.[5]

The research hypothesis concerning the association between laboratory procedures and the outcomes of digital complete dentures was not supported. Maxillary complete dentures fabricated by milling may have better retention than those fabricated by the injection-mold technique, as rated by clinicians.[3] The reason for improved retention may be related to the shrinkage-free nature of the milled PMMA.[14,43,45] Nevertheless, the

Table 4. Clinical studies on clinical visits and chairside time in relation to steps of each commercial digital denture workflow or system

Studies	Conventional Workflow	Digital Workflow					Clinical Time Difference (Saved)
	Steps (Visit)	System	Visits	Steps in Visit	Actual Mean Visits	Denture Fabrication	
Kattadiyil 2015[14]	5	Avadent	2	(Definitive impressions, interocclusal records, and tooth selection)+(delivery)	-	Not specified	205 min
Saponaro 2016[16,42]	-	Avadent	2	(Definitive impressions, interocclusal records, and tooth selection)+(delivery)	2.4	Milling	-
Schwindling 2016[3]	-	Wieland Digital Denture	4	(Primary impression)+(final impression and Jaw Relationship Record)+(Try-in)+(Delivery)	5.4	Milling	-
Srinivasan 2019[5]	5-6	Avadent	2	(Impression, gothic arch tracing, occlusal plane orientation+tooth size) and (delivery)	-	Milling	233 min
Smith 2020[2]	5	Ivoclar AG	4	(Primary impression)+(final impression and gothic arch tracing)+(Try-in)+(Delivery)	-	3D printing and milling	60 min
Arakawa 2021[6]	Not specified	Avadent and Wieland	Avadent-2, Wieland-4	Not specified in detail	-	Milling	77 min
Clark 2021[1]	5	Wagner Try-in workflow from Avadent	4	(Preliminary impressions)+(Definitive Impressions)+(Wagner Try-in)+(Delivery)	-	Milling	-
Peroz 2021[28]	5	Baltic Denture System	2	(Individualization of the maxillary Baltic Denture (BD) Key and adjustment with the BD Plane+Definitive maxillary impression [silicone]+Individualization of the mandibular BD Key+Definitive mandibular impression [silicone])+(Delivery)	-	Milling	58 min (320 min for lab)
Deng 2021[48]	5	Hoteamsoft Co Ltd	3	(Primary impression+Jaw relation record)+(definitive impression+definitive jaws relation record+esthetic try-in with diagnostic denture)+(Delivery)	3.1-3.3	Heat-activated polymerization	-
Ohara 2022[27]	5	Not specified	3	(Definitive impression+jaw relation record+gothic arch tracing)+(Try-in)+(Delivery)	~4	3D printing	2.2 h (no difference)

Table 5. Clinical studies investigating common complications and extra visits for digital complete dentures in relation to fabrication steps

Studies	Digital Systems	Visits	Trial Denture Placement	Definitive Complete Dentures Fabrication	Extra Visit Needed	Recall Visit for Complaints or Post Insertion	Remake or Repair	Pressure Sore	Loss of Retention or Need to Reline or Border Modification	Vertical Dimension or Occlusal Relationship Errors	Esthetic Complications	Fracture
Kattadiyil 2015[14]	Avadent	2	No Try-in	Not specified	-	-	-	-	-	6.6% of patients (anterior open relation)	-	-
Schwindling 2016[3]	Wieland Digital Denture	4	Performed Try-in	Milling Injection Molding	1.4	-	-	-	20% mandibular denture	2 out of 5 patients	≥2 out of 5 patients	-
Saponaro 2016[16,42]	Avadent	2	No Try-in	Milling	0.4	2.1	31.3%	Main reason for increasing recall visits	37.5% (lab reline) 12.5% (soft reline)	-	-	6.25%
Bidra 2016[17]					2 participants – additional visits	-	-	-	1	-	-	-
Schlenz 2018[19]	Ivoclar AG	4	Performed Try-in	Milling	0.6	1.7 for first 4 wk 2.07 for after 4 wk		61.0%-66.7% of follow up	20%-22.2% of follow-up (for reline)	5.6% of follow up	-	5.6%-6.7% of follow up
Drago 2019[18]	Avadent	4	Performed Try-in	Milling	-	1	Not specified		Not specified	Not specified	Not specified	Not specified
Cristache 2019[46]	3 Shape	2 or 3	No Try-in	DLP 3D printing		3.1			A reduction of retention after 18 mo			2 dentures
Cristache 2020[15]	exocad	3	No Try-in	DLP 3D printing	-	-	-	-	-	-	-	4.4% of digital dentures
Srinivasan 2021[13]	Avadent	6	Wax dentures try-in	Milling vs 3D printing	-	3D-printed denture: 3 (planned visit=1, unscheduled visit=2) (Total adjustments Milling Denture-26 3D-printed denture-40)	1: in 3D-printed denture	-	-	-	-	2-in 3D-printed dentures
Deng 2021[48]	Hoteamsoft Co Ltd	3	3D-printed trial denture	Conventional heat-activated polymerization	1 patient needs an extra visit	1.6 in student-treated groups 1.2 in physicians-treated groups	1- remake			1-unstable jaw relation	1-facial midline inconsistent with lip midline 2-highly required esthetic adjustment	

Table 5 *(Continued)*

Studies	Digital Systems	Visits	Trial Denture Placement	Definitive Complete Dentures Fabrication	Extra Visit Needed	Recall Visit for Complaints or Post Insertion	Remake or Repair	Pressure Sore	Loss of Retention or Need to Reline or Border Modification	Vertical Dimension or Occlusal Relationship Errors	Esthetic Complications	Fracture
Kim 2021[20]	Dentca denture base 2	5	Performed Try-in	3D printing	-	≥3 times - ~20% of maxillary CD ~29% of mandibular CD	28% maxillary CD 32% mandibular CD	35%	22% 2.7% stability	3.2% in occlusion	9.3%	-
Clark 2021[1]	Wagner Try-in workflow from Avadent	4	Performed Try-in	Milling	5% need additional ≥2 visits	1-2 out of 3 recalls	12.8% of digital dentures	-	-	-	-	-
Ohara 2022[27]	Not specified	3	3D-printed denture Try-in	3D printing	~1 visit	~4 (4000 seconds)	-	-	-	-	-	-

CD, complete denture; DLP, digital light processing.

objective retention of milled complete dentures was not significantly different from that of 3D-printed ones.[30,31,38,40,43,45] No superiority was specified among different fabrication techniques in most clinical and patient-reported outcomes, nor in the frequency of follow-up visits[18] or patient and clinician preference. However, the 3D-printed complete dentures are less expensive in terms of material costs and fabrication time than milled complete dentures.[2] The 3D printing technology has mainly been used to fabricate trial dentures, but the development of materials and technology has now allowed the fabrication of definitive complete dentures offering outcomes comparable with those of milled dentures.[13]

Digital dentures required around one-third of the time needed for the fabrication of conventional dentures.[28] Clinical steps can be combined to save clinical time,[5,6,14,28] and the laboratory worktime was also much reduced.[28] However, extra visits may be needed because patients or clinicians may be dissatisfied with the definitive digital complete dentures. The most common complaints about digital complete dentures were pain and pressure spots,[19,20,42] common complications in all removable dentures.[52] In addition, occlusal relationship errors,[3,8,14,16] lack of denture retention,[19,42] and poor esthetics[3] were prevalent complications that required extra visits (Table 5). After delivery of the definitive complete dentures, up to 4 visits may be needed for corrections or adjustments. However, digital complete dentures have been reported[1,18] to require fewer follow-up visits and fewer numbers of denture adjustments than conventional complete dentures.[18,20] The basic requirement of complete dentures persists, and attention to impression-making, jaw relationship recording, and esthetic parameters is key to denture success. Limitations of this systematic review included that some studies were rated as poor in quality. Moreover, heterogeneity was observed in both the study design and the investigated denture specimens. Therefore, caution must be exercised when extrapolating the results of this review to clinical practice.

CONCLUSIONS

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

1. Border-molded impression-making for recording functional denture borders is preferred for improved retention of digital complete dentures when compared with intraoral scanning.
2. Correct jaw relationship records and trial denture placement are essential in the digital denture workflow to prevent esthetic and occlusal complications. Gothic arch tracing and facebow transfer can be used to obtain accurate jaw relationship records.

3. Fabrication techniques for digital complete dentures, either milling or 3D printing, do not influence patient satisfaction, preference, or OHRQoL outcomes.

APPENDIX A. SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prosdent.2023.07.027.

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Corresponding author:
Dr Walter Yu Hang Lam
Faculty of Dentistry
The University of Hong Kong
Prince Philip Dental Hospital
3B18
34 Hospital Road
Sai Ying Pun, Hong Kong
CHINA
Email: retlaw@hku.hk.

CRediT authorship contribution statement

Khaing Myat Thu: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review and editing, Visualization. **Pedro Molinero-Mourelle**: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing - review and editing, Visualization. **Andy Wai Kan Yeung**: Conceptualization, Methodology, Validation, Writing - review and editing, Supervision. **Samir Abou-Ayash**: Methodology, Writing - review and editing, Supervision. **Walter Yu Hang Lam**: Conceptualization, Methodology, Validation, Resources, Writing - review and editing, Supervision, Project administration.

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