REVIEW ARTICLE

Conventional versus Digital Complete Dentures: A Comprehensive Review

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ABSTRACT
Complete edentulism affects many older people. For them, the main treatment is a complete conventional denture. CAD-CAM technology has now made milled and even 3D printed complete dentures. For the first time in many years there is a chance to change the entire process. Aim: To review conventional and digital complete denture processes clinically, technically, and in terms of materials and the patient. The major conclusion is that clinically and technically, digital processes reduce the number of steps and time required. First, an edentulous device is made with milled bases showing intaglio adaptation and greater retention than traditional heat polymerized bases, whereas 3D printed bases are more variable and generally less strong. In terms of satisfaction and quality of life related to the mouth and the impacts of treatment on the mouth area, digital techniques and conventional techniques have been found to be essentially equal. Intraoral scanning at edentulous areas is still not reliable at mobile soft tissues. For this reason, most current digital techniques contain a conventional final impression. The most important conclusion is to base the choice of process on the planned anatomy and aesthetics and not on technology alone. The overall conclusion is digital techniques are complete denture prosthetics that can be used as an alternative but not a replacement for conventional complete denture prosthetics. The best way to improve this area of prosthetics will probably come from larger studies that examine the replacement of complete dentures rather than just the process.
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INTRODUCTION

Complete edentulism is, unfortunately, a global issue faced by many older adults. From community-based studies of adults 45 and older, the worldwide average of complete edentulism is about 22% with a lot of variation among nations and socioeconomic groups. [1] Although the worldwide age-adjusted prevalence of severe tooth loss decreased between 1990 and 2010, the actual number increased due to substantial population growth and aging. [2] complete edentulism represents much more than just missing teeth. There are significant issues related to chewing (mastication), facial appearance, nutrition, as well as loss of quality of life. [3] Edentulism, therefore, is a substantial and important issue for any prosthodontist[4].

Computer-aided design and computer-aided manufacturing (CAD/CAM) came to removable prosthodontics later than to fixed prosthodontics[5]. The first published report of a CAD/CAM system for complete dentures was in 1994,[4] although clinical interest arose after the marketing of milled denture systems some 20 years later. Through an assessment of the historical literature, the primary issues were deemed to be the capture of accurate data pertaining to the edentulous arch and the transformation of the maxillomandibular relationship to a virtual environment.[6] Subsequent research defined the clinical methods that would capture the data within a digital system.[7] Thereafter, milled and additively manufactured dentures became routine in clinical practice[8].

Reports of systematic reviews indicate no statistically significant difference between CAD/CAM complete dentures and traditional complete dentures for majority of the measured dimensions, and suggest advantages of CAD/CAM complete dentures in several mechanical and surface properties and in preserving a digital record.[7] Clinical studies suggest CAD/CAM complete dentures have better retention and require less working time.[8] Excessive interest has been generated, e.g., intra oral scanning of the completely edentulous arch, which is presented as the hallmark of the digital workflow, records mobile soft palate and peripheral tissues inferiorly compared to attached mucosa, and cannot replace a functionally border-moulded impression.[9] The manufacturing technique also plays a role; although CAD/CAM dentures are commonly grouped as ‘digital’

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applications, milled and 3D-printed dentures are very different in accuracy, strength, and surface behavior[10].
This review aims to analyze different factors in the conventional and digital complete denture processes, describe where milled and 3D-printed prostheses can be differentiated, and identify where each method is justified based on clinical situations.

The Conventional Complete Denture Workflow

The conventional workflow is presented in Figure 1. A stock-tray impression is done to record the denture-bearing region and adjacent structures and is used to construct the primary cast. A custom tray is made. The definitive impression is taken in the custom tray after border moulding. The impression needs to record the denture-bearing region and achieve a seal to be intact during functional movement. Defects at this stage will propagate to all following steps, and lack of adequate border extension is the principal reason for retention failures at the time of insertion [3].
Dimensional accuracy is most problematic during the laboratory phase. All dimensions shrink to some degree during polymerization of the methyl methacrylate resin. During seating, the texture of the finished denture rubs against the master cast.[11] This results in the greatest discrepancy in the posterior maxillary region and highly vaginal palatal region. During fabrication, most processing errors occur in the relation of the occlusal surfaces. These can be corrected by remounting and selective grinding of the occlusal surfaces[12]. During the insertion visit, the patient is evaluated for sore spots and occlusal discrepancies[13]. The fit surface of the denture is evaluated with pressure-indicating medium. Adjustments to the occlusal surface are made and the patient is evaluated at regular intervals. Multiple appointments are the norm rather than the exception[14].

The Digital Complete Denture Workflow

Figure 2 describes a workflow that shifts patient data capture to the first step in the process, where three workflows currently exist. In the most common workflow, a conventional definitive impression is scanned by an extraoral scanner in a laboratory to digitize the functional border record and transfer the geometry into a digital workspace. In the second workflow, a satisfactory duplicate of a denture is scanned and used as the original. In the final workflow, edentulous arches are captured by intraoral scanning[15].
Of the three workflows, intraoral scanning is the most attractive, but also the least developed. A systematic review on clinical and in vitro studies indicated that trueness across attached mucosa and defined anatomical landmarks when scanning intra-orally was consider equivalent to an impression, however larger measurement discrepancies were observed when scanning the peripheral border, posterior palatal seal area, and the soft palate where lack of stable points and non-retracted mucosa, respectively, inhibited image stitching and scanning in a functional state. Intraoral scanning is, therefore, not recommended for use in situations of retention that is reliant on tissue displacement or in cases of unfavorable ridge anatomy, and most digital denture systems maintain a conventional definitive impression[16].
Maxillomandibular relationships are recorded on a prefabricated, customized base using either gothic arch tracing mechanisms or scannable markers which are then transferred to a virtual articulator[17]. The design is completed in special software. The digital cast is trimmed, the denture bearing area and previously made post-dam are identified, an intaglio offset is placed, and teeth are positioned from a digital library or with teeth placement algorithms within the limits of ridge and occlusal position[18].
At the CAM stage, the two primary processes diverge, and this divergence is central to any evaluation. Subtractive manufacturing completely manufactures the denture base and, in some systems, fabricates the denture completely from an industrially cured PMMA disc[19]. Teeth are bonded to the sockets manufactured in the base or integrated in a monolithic prosthesis. With additive manufacturing, the base is fabricated layer by layer from a photopolymerizable resin, then washed and post-cured[20]. Teeth may be manufactured separately and bonded to the base or fabricated conventionally [11,12]. The most common option, for cost reduction and acceptable aesthetics, is a printed base with prefabricated teeth [13]. Regardless of the path taken, the design file is maintained, thereby allowing a prosthesis of identical design to be manufactured without the clinic needing to repeat the process.
As with the other stages of this process, finishing and characterisation are conventional, albeit with more limitations compared to the wax-up trial denture stage.
A printed or milled trial denture may be placed while waiting for a final production. In this case, the milled

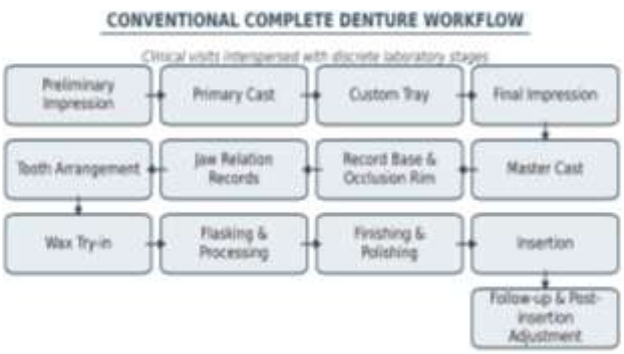

Figure 1. Conventional complete denture workflow

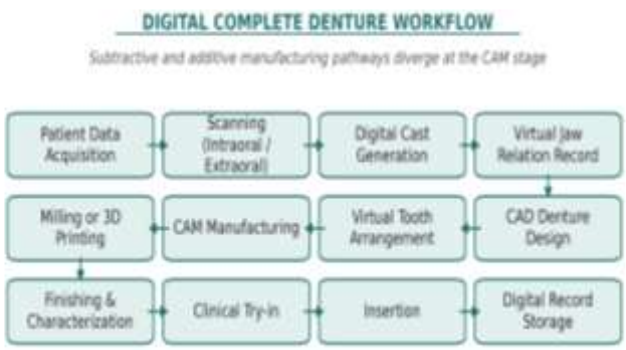

Figure 2. Digital complete denture workflow

Table 1. Comparison of conventional and digital complete denture techniques

Parameter	Conventional denture	Digital denture	Clinical implication
Clinical appointments	Typically, 5 visits	2–4 visits, protocol dependent	Fewer visits benefit frail, remote or time-limited patients
Chairside and laboratory time	Longer overall; several discrete laboratory stages	Reduced clinical time; laboratory work largely automated	Improved throughput, though design time is transferred to the operator or technician
Definitive impression	Border-moulded custom tray; functional peripheral record	Conventional impression scanned extraorally, or direct intraoral scan	Intraoral scanning of edentulous arches remains least reliable at mobile borders
Maxillomandibular records	Wax occlusion rims; operator dependent	Prefabricated or scanned record bases; digital transfer	Digital records are reproducible but still rely on a correct clinical registration
Denture base adaptation	Affected by processing shrinkage and deflasking	Milled bases show the closest intaglio adaptation; printed bases are more variable	Adaptation differences are measurable in vitro; clinical relevance is modest
Retention	Adequate in most patients	Higher measured retention for milled bases	Meaningful mainly in maxillary arches with compromised anatomy
Dimensional accuracy	Polymerization shrinkage of approximately 0.2–0.5%	Milling avoids shrinkage; printing introduces build-angle and post-cure effects	Manufacturing pathway, not digitisation itself, governs accuracy
Mechanical properties	Heat-polymerised PMMA; well characterised	Milled PMMA highest flexural strength; printed resins variable and often lower	Milled bases preferred where fracture risk is high
Residual monomer	Higher; depends on curing cycle	Low in milled discs; printed resins depend on post-curing	Relevant to mucosal irritation and reported monomer sensitivity
Surface characteristics	Roughness increases with finishing errors	Milled surfaces smoother; printed surfaces show layer texture	Influences biofilm accumulation and staining
Aesthetics and characterisation	Highly customisable at wax try-in	Constrained by software libraries; individual characterisation more difficult	Conventional methods retain an advantage in demanding aesthetic cases
Patient satisfaction	Consistently high in adapted patients	Comparable; no consistent superiority demonstrated	Satisfaction should not be the sole basis for selecting a workflow
Reproducibility and records	Duplication requires a new clinical sequence	Stored design files permit rapid duplication	Valuable for loss, fracture or repeated replacement
Cost	Lower capital outlay; higher recurring labour	High initial investment; lower per-unit labour	Cost advantage depends on case volume and reimbursement setting

PMMA, poly(methyl methacrylate)

denture, being fabricated from the same design file as the printed one, can function as a real prototype. Although there is slight differences between the performance of milled and printed dentures, favouring milled dentures over printed dentures in terms of intaglio trueness has been reported in the literature [21]. As with others, the principles of insertion hold. The reduced number of appointments is achieved by compressing or eliminating stages rather than by removing clinical judgement [15].

Comparison of Conventional and Digital Complete Dentures

Figure 3 contrasts the two sequences directly, and Table 1 summarises the parameters discussed below.

Workflow, appointments and cost

Efficiency is the advantage most commonly seen across multiple studies of digital fabrication. When comparing pre-doctorate studies, digital methods required fewer appointments and less total time for treatment than conventional methods for comparable prostheses [15]. A university-based time and cost study demonstrated that the two-visit milled denture protocol significantly reduced clinical time when compared with the conventional protocol in which a lot of time was saved by avoiding separate appointments for try-in and record [16]. A retrospective clinical audit showed similar results and noted that the savings in the cost of time and labor were mitigated by expenses for the laboratory and licensing [17]. Thus, in different contexts, digital workflows displace the cost of labor by purchasing capital equipment and license costs, so the costs are justified in high-volume practices but are not justifiable in low-volume practices.

Impressions, records and occlusion

Conventional impression making is superior to digital impression making when it comes to achieving accuracy. When using border-moulded custom trays, impressions are made in a functional state. In contrast, intra oral scanners will record impressions in a static state with greater error.[9] Maxillomandibular registrations will be the same in both processes. Digitization may increase the reproducibility of the stored and transferred record, but does not reduce the error of the record[22]. In a randomized, controlled, blinded study looking at the placement of complete digital and traditional dentures, there was no difference in the functional and occlusal outcome. The authors claimed that the quality of the clinical record trumped the fabrication method[23].

Adaptation, fit, retention and stability

Denture base adaptation has been studied. When comparing milled bases to conventionally processed bases, shrinkage during the polymerization process is absent in industrially processed resin discs[13]. This results in milled bases adapting more closely to anatomical features of the intaglio surface. Digital light processing of bases has shown adaptation to the stress bearing region of the intaglio surface within clinically acceptable range for the maxillary and mandibular arches. Printed bases adapted well, with milled maxillary bases exhibiting small marginal gaps[18]. There have been several clinical studies on the intaglio surface of milled and printed dentures, showing trueness and results within clinically acceptable ranges, with differences exhibited more in the maxillary region than the mandibular region. When comparing ridge form and stability, there has been no evidence to show any appreciable differences[24].

Materials, dimensional accuracy and surface behaviour

Dimensional accuracy is governed by the manufacturing pathway rather than by digitisation. Milling from a pre-polymerised disc avoids polymerisation shrinkage entirely, while additive manufacturing introduces its own error sources including build angle, layer thickness, resin shrinkage and post-curing protocol; in vitro comparison found milled dentures truer than printed dentures at the intaglio surface [14]. Mechanical properties follow the same pattern. Meta-analysis of in vitro flexural testing found milled denture base materials to be comparable or superior to heat-polymerised PMMA, with printed materials generally inferior [23]. A more recent meta-analysis reported the highest flexural strength and surface hardness in milled bases, intermediate values in conventional PMMA and the widest variability in printed bases [24]. Residual monomer content is lowest in industrially polymerised milled discs and is strongly dependent on post-curing in printed resins [12], which is relevant both to mucosal tolerance and to water sorption. Surface roughness is lowest in milled bases; printed surfaces retain layer texture that requires careful finishing, with consequences for biofilm accumulation and staining [7]. These are in vitro findings, and the magnitude of their clinical effect over years of service has not been established.

Aesthetics, comfort and satisfaction

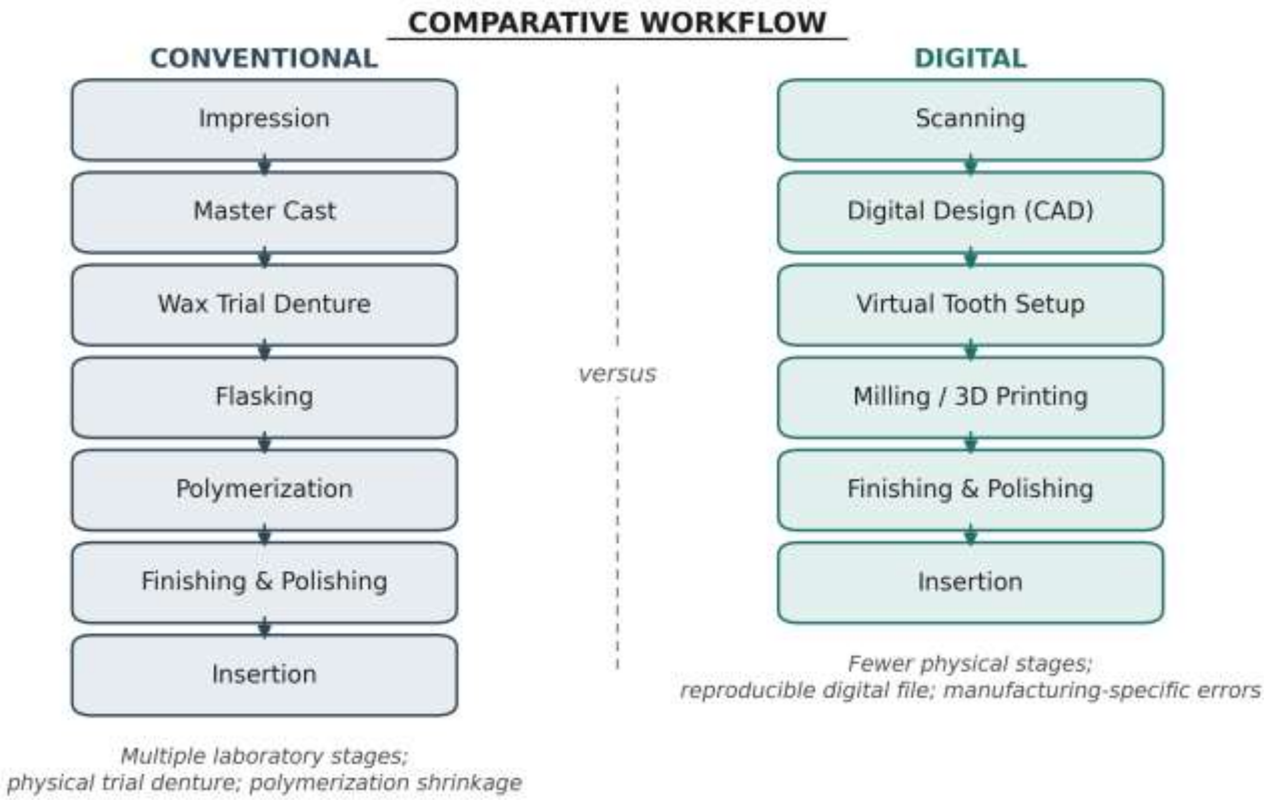

Figure 3. Comparative workflow of conventional and digital complete denture fabrication

Aesthetic personalization adheres to the standard workflow, The wax trial denture allows for completely uninhibited modification of position of teeth, contour, and characterization of gingiva, compared to digital design, which is limited by tooth libraries and by the complexity of personalizing a monolithic prosthesis. Based on patient-reported outcomes, neither technique shows an advantage[20]. A study conducted on patients who were treated with CAD-CAM dentures reported high comfort and fit satisfaction and speech accommodation. A meta-analysis on comfort and fit satisfaction showed that the digital dentures were more cost effective, but the outcomes varied between studies. Obviously, none of the studies showed that one approach was definitively better than the other[14]. This suggests that digital dentures are economically superior but DSD and wax try-in technique will provide the most accurate results.

MATERIALS USED IN DIGITAL COMPLETE DENTURES

Milled dentures

High-quality PMMA polymerization results in dentures that have a very high degree of crosslinking and a highly homogeneous structure with low porosity and negligible residual monomer. Polymerization occurs at elevated temperatures and pressures, and since it is complete prior to machining, a base milled from PMMA will have no shrinkage from machine processing [13]. As a result, milled bases show high flexural strength, surface hardness and low surface roughness [23,24]. The limitations are mainly procedural rather than material: subtractive processing, or machining, is wasteful of material, cannot duplicate undercuts beyond the reach of the bur, and is a significant financial investment. It is more difficult to achieve an aesthetic representation of a monolithic milled prosthesis as compared to building up layers in wax.

Three-dimensionally printed dentures

Printed dentures are typically made using photopolymerisable methacrylate based resins which are fabricated either by Stereolithography or Digital Light Processing and require a solvent wash and controlled post-curing. Compared to traditional forms of denture fabrication, additive manufacturing is more cost efficient, easily produces dentures of complex geometry and is able to fabricate multiple prostheses in a single build[16]. However, the mechanical properties of additively manufactured dentures are dependent on factors such as build strategy, layer thickness and post-curing. Printed denture bases show the lowest flexural strength, hardness and fracture toughness. The performance of printed prostheses is also dependent on residual monomer, which is removing unwanted uncured resin by post-curing, and prints exhibit layer related surface texture. For the aforementioned reasons, printed bases and denture teeth are often fabricated separately and adhesively joined[20].

Comparison with heat-polymerised PMMA

Conventional heat-polymerised PMMA is a low-cost material that continues to be used as a benchmark. PMMA is easily repaired and well tolerated, and with decades of clinical service, it is an established material. Its main shortcomings are dimensional changes associated with polymerisation [10] and higher residual monomer than milled material [25]. In the current state of the available in vitro data, milled bases outperform conventional PMMA.

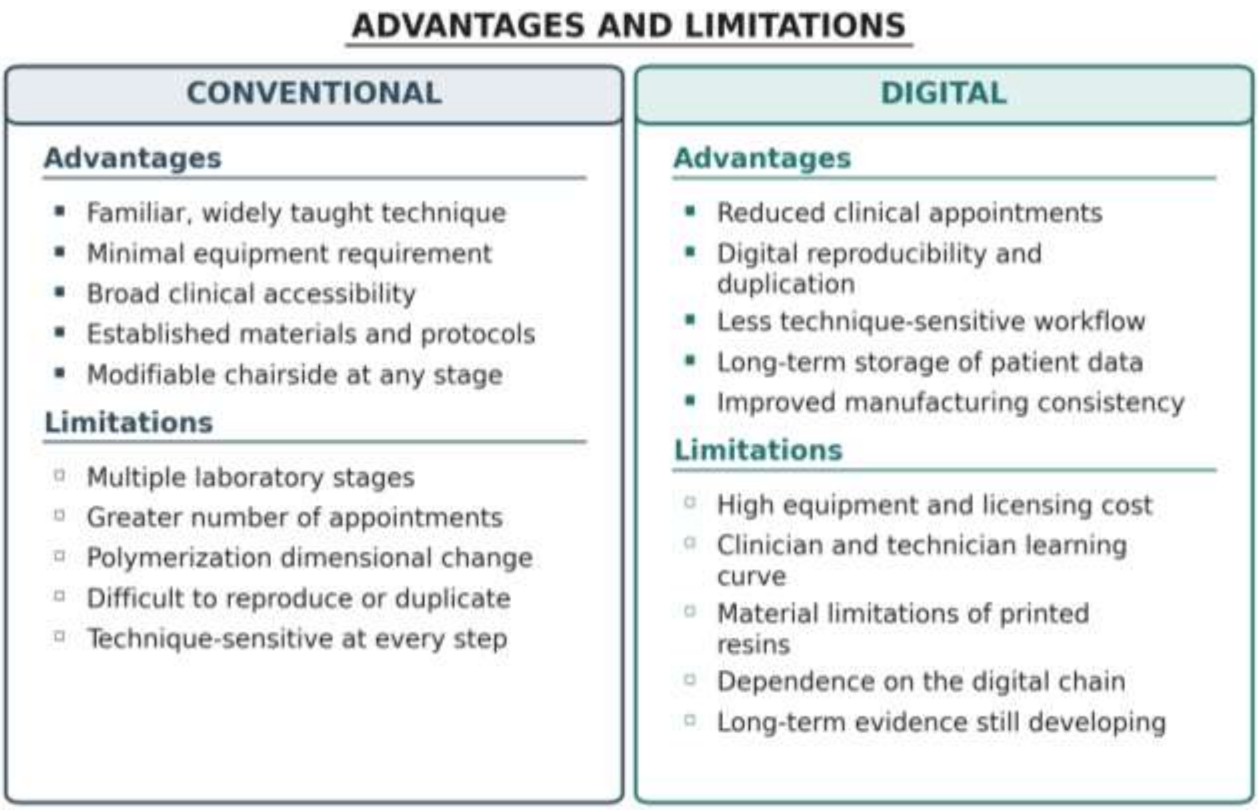

Figure 4. Advantages and limitations of conventional versus digital complete dentures

Conventional PMMA outperforms most printed resins in strength and hardness [24]. However, printed resins have the fastest technological development among the three and comparisons made more than 2 or 3 years ago should be avoided.

ADVANTAGES AND LIMITATIONS

Figure 4 offers a summary of advantages and disadvantages of the two approaches. Conventional dentures maintain the benefits of familiarity, low expense, and ease of access and can be altered manually at every stage, but are restricted by the number of appointments, cumulative laboratory errors, polymerization shrinkage and duplication. Digital dentures reduce the number of appointments and provide a durable patient record and consistent manufacturing; their restrictions lie in the capital cost and a steep learning curve for both clinician and technician. The use of printed resins places material restrictions. Digital dentures rely on an uninterrupted digital chain. An evidence base is lacking in both areas, in particular, follow-up [7,29]. Neither list provides a definite solution, which is why the selection of a case should determine the choice rather than preference of technology.

Clinical Outcomes and Patient Satisfaction

Small clinical studies and retrospective audits with short follow-up periods provide most of the evidence for both methods. A meta-analysis of six studies found CAD-CAM dentures had better retention, shorter fabrication time, and no difference from conventional dentures for quality of life; retention was better for CAD-CAM dentures with a standardized mean difference of 0.501; however, high between-study variability was noted [8]. A blinded randomized control trial demonstrated analogous clinical results for digital and conventional dentures [18].

Masticatory efficiency and speech and oral health outcomes haven't been studied as frequently. In a systematic review and meta-analysis of clinical performance and patient-reported outcomes, digitally fabricated dentures were found to perform equivalently to conventional dentures, with benefits of digitally fabricated dentures observed to be primarily in terms of efficiency rather than in terms of function [5]. An earlier systematic review of clinical performance reached the same conclusion and warned that the studies considered together were much too heterogeneous to support any strong conclusions [9]. Collectively, the studies support equivalence with efficiency gains and do not support clinical superiority. Individual studies often contradict each other. These conflicts have more often than not been due to differences in the system, operator experience, and outcome measurement. When looking at technology in isolation, there have been no real contradictions.

CURRENT EVIDENCE AND FUTURE DIRECTIONS

The next ten years will see changes in clinical practice that we can begin to anticipate. We can begin to assess these changes in practice in the light of what we now already know. One systematic review of AI models in prosthodontics showed some models did perform well in laboratory-based studies. A review of studies in the removable prosthodontics subspecialty noted laboratory-based studies in design automation and outcome prediction, and noted a shortage of externally validated studies [8]. In the short to medium term, these technologies will help reduce variability in design. They will not replace clinical decision making.

Until intraoral scanners can capture mobile peripheral tissues in their functional state, fully digital impression based workflows will remain restricted; this is more to do with the behavior of tissues than the resolution of scanning equipment, and incremental improvements in scanning equipment are not likely to address this[15]. The combination of 3D facial scanning and virtual articulation provides a rational approach towards more individualized aesthetic and occlusal design, although this is currently based on a paucity of evidence, i.e., reports of techniques and small, comparative studies[21].

Quickly advancing developments in printable denture materials decrease the gap between printed and milled mechanical performance [11,24]. Chair-side fabrication, remote laboratory collaboration and duplication from stored files are all technically possible today and are likely to become common before the development of the needed algorithms. The simplest, but possibly the most valuable, near-term application of the digital record is to enable the rapid replacement of a lost or fractured denture for a patient where a repetition of a five-visit process would cause significant difficulties[15].

CONCLUSION

Conventional complete dentures still have accessibility and a long track record during difficult cases. Digital complete dentures can be even more efficient and offer better retention when milled and create a patient record that allows the denture to be copied. However, limitations do still apply. In fact, digitally scanning an edentulous arch still is not the same as a functional impression. Furthermore, patient-reported outcomes haven't shown superiority for any of the techniques.

Lack of complete digital systems means that the hybrid systems currently in practice reflect that accurately. Longer, 5+ year randomized control trials are necessary to evaluate the outcomes of the different systems in order to provide more evidence based conclusions.

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