Digital removable complete denture: a narrative review

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Abstract:
Removable complete dentures have recently entered the digital area, through various workflows constantly evolving with the maturity of digital technologies. Indeed, practitioners and laboratories are particularly challenged with the integration of digital tools and techniques in the daily treatment of complete edentulism. The aim of this narrative review was to summarise the current knowledge about digital removable complete dentures, to enable practitioners and laboratories to decide either to move to a fully digital workflow or to integrate some of these new tools into their current practice. The first part of this article reviews different techniques for recording edentulous ridges and the maxillo-mandibular relationship. Then, the second part describes the digital steps involved in designing prostheses, while the last part describes the materials and manufacturing technologies. As a conclusion, digital technologies provide several options for the treatment of edentulous patients, but there is a need for remaining vigilant on the quality of the delivered prostheses and treatment.

Key words: *CAD/CAM, additive manufacturing, milling complete dentures, intraoral scanner, digital denture, digital impression, 3D printing, digital workflow*
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INTRODUCTION

The removable complete denture (RCD) is the most common rehabilitation of edentulous patients worldwide.[1-4] Protocols for the fabrication of RCDs following the traditional workflow consist of registering the geometry of supporting tissues and peripheral musculature (through one or two impressions), recording the maxillo-mandibular relationship, designing the denture (with tooth arrangement), try-in, fabrication and insertion. This prosthetic chain is a succession of clinical and laboratory steps involving multiple operators, and consequently, prone to errors.[5-7]

The development of computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies is profoundly changing complete denture treatment. Edentulous ridges and maxillo-mandibular relationships can nowadays be recorded with intra-oral scanners (IOS), RCDs can be digitally designed through multiple commercially available software, and traditional flasks can be replaced by milling and printing machines.[8-17] More importantly, these technologies can guarantee for the first time a reproducible manufacturing quality. However, the diversity of tools and protocols complicates their integration into daily practice, especially since they have not all reached the same level of maturity. Nevertheless, the digital transformation is gradually revolutionising complete dentures.[18]

The objective of this narrative review was to summarise the current knowledge about digital RCDs through a presentation of currently available devices and technologies to produce removable dentures and implant-supported dentures for edentulous patients.

Digital impression for RCD

A digital scanner is a non-contact measuring device that records and reconstructs three-dimensional (3D) surfaces or volumes.[16,19] It consists of an optical acquisition system in association with a 3D reconstruction software (*Figure 1*). IOS are mobile and record directly in the mouth, while extra-oral scanners (EOS) are used to digitise impressions/models in laboratories. Facial scanners can be used for recording aesthetic lines or extra-oral defects in maxillofacial prosthetics.

Digital scanning of edentulous ridges

Scanning of edentulous arches presents three recording challenges: the lack of anatomical landmarks, the functional borders,[20] and the posterior palatal seal. Intraoral scans allow preliminary non-compressive digital scanning of the ridges.[8-12] However, it is necessary to follow specific scanning protocols to record areas without anatomical landmarks such as the palate or edentulous ridges.[20-23] Placement of composite markers or use of a dermal marker on the mucosa facilitates the impression.[21,24,25] A custom impression tray can then be fabricated from this preliminary impression to make a conventional final impression. The accuracy of digital scanning is similar to that of conventional materials in the maxilla, with 0.70 ±0.18 mm for IOS, 0.75 ±0.17 mm for polyvinylsiloxane and 0.75 ±0.19 mm for eugenol zinc oxide-modified polyvinylsiloxane.[26] However, these results remain to be confirmed for the mandible as well. Borders stretching is the most difficult area to record with digital scanning.[21,25] Jung *et al.* proposed to match conventionally registered functional borders with the original digital scanning.[27] Other authors proposed mobilising soft tissues with a finger or a mirror to record their position.[22,24,25] Concerning the posterior palatal seal, the anterior and posterior vibrating line on the soft palate could be delineated by using an indelible pencil or small spots of light-polymerised gingival barrier material before scanning.[21] The accuracy of digital scanners is sensitive to other factors such as learning curve, brightness during scanning, presence of saliva or scanning strategy.[28-33] Each IOS requires specific settings and training.

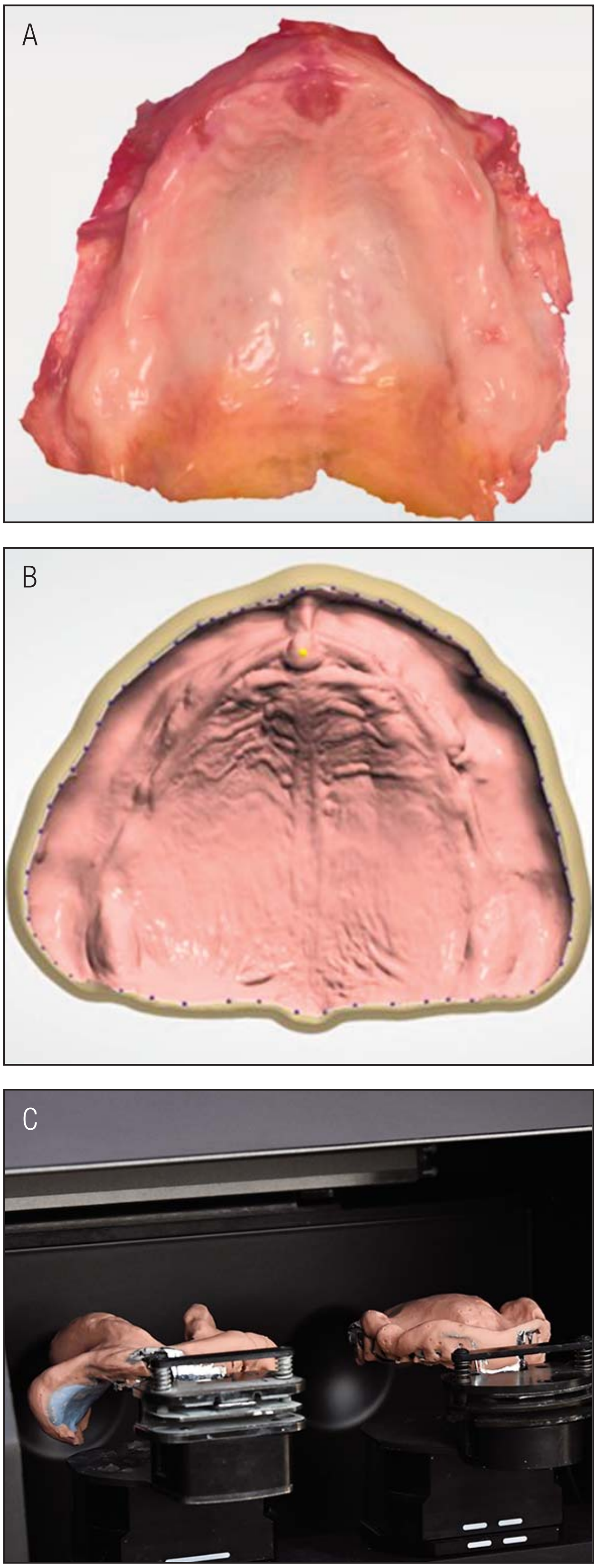
Digital impression of implants

Scan bodies used in digital scanning for implant-supported prosthetic rehabilitation are landmarks on edentulous ridges. However, the similarities between the landmarks create a risk of confusion for the reconstruction algorithm when individualising each implant.[34,35] Two technologies were proposed for digital scanning of implants: confocal microscopy (IOS) and stereo photogrammetry.[36] Both systems were documented in short-term clinical studies and the conclusions were similar: satisfactory survival rate after 1 to 2 years and clinical and radiological passivity of the prosthetic frameworks.[37-39]

Several *in vitro* studies measured the accuracy of digital scanning for distance and angulation, and recent IOS offered superior or equal results when compared to conventional impressions.[40-47] However, caution is needed when interpreting these measurements because deviations measured *in vivo* could be doubled compared to *in vitro* measurements.[48]

The accuracy of digital scanning is improved when the inter-implant distance is short,[49] the scan bodies are high and simple in design, the operator is experienced[50] and complies to the manufacturer's recommended scanning strategy.[37,45,50,51] However, implant angulation, depth, and type of connection do not

Figure 1: Strategies to obtain digital scans of edentulous patients, using an intraoral scanner (A), or by digitisation of the prothesis (B) or the cast (C)



influence the accuracy.[45,52,53] Similarly, implant transfers splinting does not increase accuracy.[49,54] Finally, a digital scan is twice as fast as a conventional impression, with the possibility of partial retake.[39] These recommendations were validated for digital scanning of 4 to 6 implants in both the maxilla and the mandible. On the other hand, the optical impression is not yet validated for overdentures on two implants.[55]

Extraoral scanners

Many laboratories already use EOS in their daily practice to scan impressions and models. Regardless of the measurement acquisition technology (laser, structured light or contact), a software program generates a 3D reconstruction of the object and an STL file that can be used in most CAD software programs. Although the performance of IOS and EOS are close,[56] EOS is generally considered more accurate than IOS because of the conditions controlled during acquisition (temperature, light and humidity).[19,57,58] Optical scanners are faster than contact scanners due to the controlled conditions, but they could be affected by the optical properties of the scanned object.

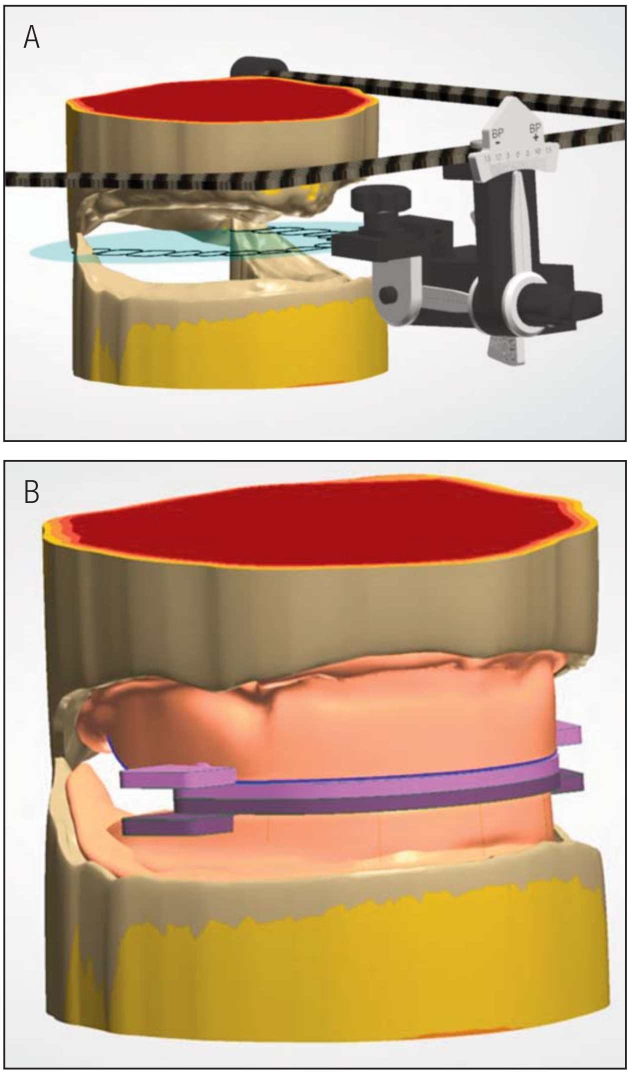
Facial scanners

The digitalisation of the face was proposed by some authors to improve denture design and facilitate communication.[26,59,60] The facial 3D file could, in theory, be matched with the edentulous ridge file, but this combination has not been described yet.

Maxillomandibular relationship record

None of the currently available workflows is entirely digital for recording the maxillo-mandibular relationship; all approaches rely on conventional or 3D-printed baseplates supporting wax occlusion rims.[61-65] In the Ivoclar-Vivadent® workflow, the maxillo-mandibular relationship is recorded in two steps. First, the practitioner records the preliminary impressions conventionally and a preliminary jaw relation with a specific device. After connection, the whole set is then scanned in the laboratory with an EOS,[13] and positioned on a virtual articulator (*Figure 2*). The occlusion rims are then digitally designed in a position close to the clinical situation, facilitating the final recording.

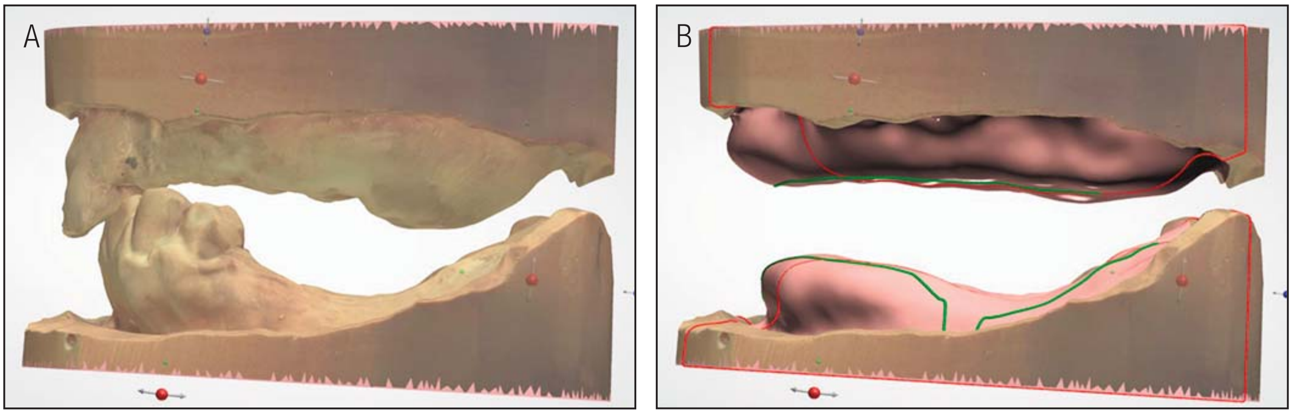
Figure 2: Maxillomandibular relationship record. Digital transfer of the preliminary jaw relation (A) and design of the occlusion rims (B)



For the realisation of occlusion rims, the CAD software is able to detect the anatomical landmarks on the ridges to visualise the situation of the future prosthetic teeth (centre of the incisal papilla, maxillary tuberosity, labial frenulum, retromolar trigone). The occlusal rims may be designed for a maxillo-mandibular co-adaptation procedure or to receive devices such as central bearing tracing.[13,14,22] In this case, the height of the occlusal rim will be underestimated to facilitate device

Figure 3: Computer assisted design of complete denture. The software offers an automatic proposition of maxillar and mandibular tooth alignment (A), that could be modified following anatomic landmarks (B). The digital set-up could also be matched with a picture of the patient to improve communication and esthetic outcomes (C).

Figure 4: Illustration of the virtual protocol of immediate denture design, before (A) and after digital extraction and ridge modelling (B)



placement and registration. Other authors prefer silicone bite registration and a secondary scan in the laboratory (EOS) or directly with an IOS.[17,24,26,65]

Computer-assisted design of complete denture

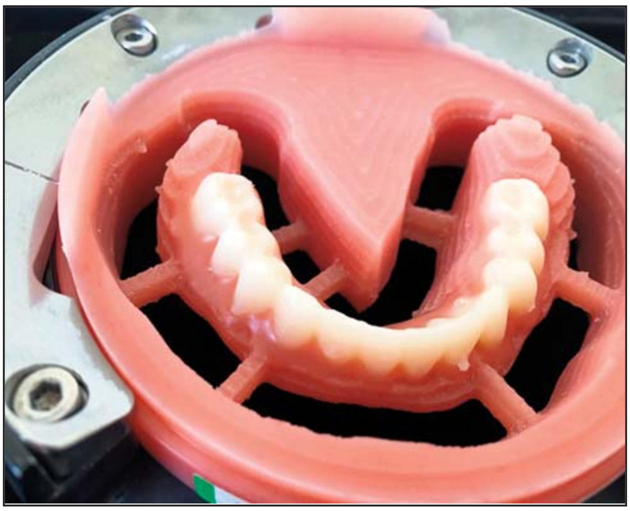
Numerous software programs were developed specifically for RCD: 3Shape Dental System®, Ceramic D-Flow®, Exocad®, Lucy®, Dental Wings®, 3Shape Digital Denture®, Modifier®. These digital tools are increasingly used in dental laboratories independently from the dentist's clinical workflows, as they save time, increase accuracy and reproducibility of RCD.[65,66]

CAD of complete denture: prosthetic bases and teeth

The software includes teeth libraries of different brands and shapes, yet it is also possible to personalise the shape of teeth according to the needs of the set-up (morphological tooth adaptation).

The occlusal plane and the insertion axis of the denture are defined according to anatomical landmarks (*Figure 3*). The software then automatically proposes a bilaterally balanced set-up, which significantly saves time when compared to conventional techniques.[67] The operator can then customise the set-up by modifying the position of one or more teeth, or even remove them. The virtual articulator allows static and dynamic occlusal analysis. Finally, the volumes, the dimensions of the papilla and the canine eminences, the marginal curve, and the finish can be adjusted. The files are then prepared for the production of the denture and/or templates for try-in and functional validation of the set-up.[67] These templates can serve as transitional dentures in the treatment of patients with temporomandibular disorders or can be used as radiological and/or surgical templates for a subsequent implantation project.[67]

Figure 5: Computer assisted manufacturing of complete denture, using a milling machine



CAD of the single-arch RCD

In these rehabilitations, occlusal balance is essential. Several software programs offer an ideal teeth assembly and indicate the corrections to be made in the antagonist arch. This allows the operator to easily switch from the ideal set up to a set up without modifying the antagonist arch. As with the anterior teeth, the size and shape of the teeth can be customized to facilitate occlusal balance.

CAD of immediate RCD

With new tools such as digital extraction, the practitioner also handles the transition to complete edentulism.[68-70] The working model is prepared by superimposing the model with the patient's CBCT for post-extraction crest modelling.[60] A duplicate of the future immediate RCD can also serve as a surgical guide. The patient's face can be integrated into the model using photographs or facial scans to optimise the determination of the interincisor point.

It is also possible to superimpose the patient's RCD and their residual teeth during the design. The objective is to position the interincisal point according to its optimal situation and to facilitate the choice of tooth shape and size (*Figure 4*).

Design of implant-supported framework

The use of CAD/CAM processes for the fabrication of implant infrastructures has been used for decades. New materials, not available for traditional casting techniques, have appeared with increased biocompatible and aesthetic properties.[71] In-

Figure 6: Examples of denture characterisation using pink composite

deed, zirconia is easily machined into pre-sintered blocks and the design software effectively compensates for sintering shrinkage.[72] However, the mechanical properties of the metal are superior when the framework is milled from industrial blocks with fewer micro-defects, porosities and impurities.[73] Deformations and stresses stored in the material disappear as there is no longer any need of the cooling phase.[72] The fitting accuracy is less than 150 µm, which guarantees the passivity of the implant framework.[74] In addition, these techniques are less operator-dependent, more reproducible, and at a lower cost than the casting of precious alloy frameworks.[72] It should be noted that these CAD/CAM frameworks do not tolerate brazing and cannot be modified.

Computer-assisted manufacturing (CAM)

New manufacturing processes have also influenced the materials used in the manufacture of RCDs. The main and universally used component is polymethyl methacrylate (PMMA). Its exothermic polymerisation causes material shrinkage. In the conventional process, strict control of temperature, pressure and polymerisation time improve the material homogeneity and integrity of the denture surface, and also reduce the shrinkage and porosities. However, these traditional protocols were operator dependent. Fabrication of RCDs, whether by milling or 3D printing, reduces these sources of error (*Figure 5*).

Computer-assisted milling of complete denture

Milling from polymerised resin discs is the most developed CAM process. The inversion of the shaping and polymerisation steps removed shrinkage difficulty and shifted the quality control of the polymerisation process to the manufacturer. The main clinical consequence is the excellent fit of the denture on the supporting tissues, with increased comfort and better retention.[15,75-77] It also became possible to optimise the composition of the materials in order to improve their mechanical properties (flexural strength, fracture resistance, hardness) and biocompatibility.[78-80] However, the properties of resin materials commercially available vary considerably and do not currently represent a uniform class of materials.[76,79,81]

Although milling processes are currently the most widely used, they nevertheless have economic and environmental costs, since a large part of the disc is not used.

Computer-assisted printing of complete denture

Additive processes thus seem very promising.[82] 3D printing consists of shaping the dental prosthesis by successive addition of material.[16] Stereolithography (SLA) or digital light processing (DLP) achieve satisfying precision with resin layers from 20 to 150 µm thick, which are compatible for the manufacture of the base and/or the teeth.[83] Several commercial systems, such as Dentca CAD-CAM (DENTCA Inc) or Pala (Kulzer) digital denture, already propose medical devices and clinical protocols.[84-85] It is also possible to print dentures directly with CE marked Class IIa resins (Next-Dent B.V. and Envisiontec Inc). First, the base is printed with compartments to glue the printed dental arch or commercially available teeth.[84-85] Repositioning of the teeth is then facilitated by a printed transfer key.[26] 3D printing must still be used with caution when making a final RCD, due to the lack of clinical evidence regarding mechanical properties, wear resistance, ageing and biocompatibility.[86] Indeed, it appears that the accuracy of the printed RCD is lower than that of milling, but remains clinically acceptable, satisfies patients, requires less equipment and less sophisticated machinery than milling.[86-87] Finally, milling or 3D printing gives monochrome shades to the bases and prosthetic teeth, which may require the laboratory team to stain with different shades of pink composite (*Figure 6*).

CONCLUSION

There is still room for improvement in the digital workflows for complete dentures. Many procedures are interestingly available for clinics and laboratories. These tools can already be partially integrated into one or more stages of treatment but the full digital workflow for the edentulous treatment is not entirely validated. However, with the current evolution of imaging, biomaterials and CAD/CAM, the prospects for digital removable complete dentures are promising. Finally, even if the cost of these devices could be a limitation in the past, some efforts have been made by companies to adapt to market capacities, which will facilitate the dissemination of these technologies.

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