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Joda, T, Ferrari, M, Gallucci, GO et al. (2 more authors) (2017) Digital technology in fixed implant prosthodontics. Periodontology 2000, 73 (1). pp. 178-192. ISSN 0906-6713

https://doi.org/10.1111/prd.12164

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Running Title:
Digital implant prosthodontics

Monograph & Guest Editors:
Modern implant dentistry celebrating 50 years of osseointegration
Buser, Sennerby, De Bruyn

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Digital technology in fixed implant prosthodontics

Abstract

Digital protocols increasingly influencing prosthetic treatment concepts. Implant-supported single-unit and short-span reconstructions will benefit most from the present digital trend. Monolithic implant crowns connected to pre-fabricated titanium abutments starting with IOS and combined with virtual design and production without any physical master casts have to be considered in place of conventional manufacturing in posterior sites. Subsequently, no space for storage is needed in the complete digital workflow, and in case of renewal, a copy of the formerly reconstruction can be fast and inexpensively produced by means of rapid prototyping. The technological progress is split in subtractive methods, as milling or laser ablation, and additive processing, as 3D printing and selective laser melting, respectively. Individualized supra-implant soft tissue architecture can be calculated in advance according to a morphologic copy. All these technologies have to be considered before implementing new digital dental workflows in daily routine. The correct indication and application are a prerequisite and crucial for the success of the overall therapy, and finally, for a satisfied patient. This includes a teamwork approach and equally affects the clinician, the dental assistance, and the technician as well. The digitization process will change the entire dental profession. Major benefits will arise to reduce production costs, improve time-efficiency, and to satisfy patients' perceptions of a modernized treatment concept.

Keywords: dental implant, fixed prosthodontics, digital workflow, technical application, esthetics, economics, rapid prototyping

Introduction

A restoration-driven treatment concept is the key factor for successful implant therapy in an interdisciplinary team approach of prosthodontics, periodontology, surgery, radiology, and dental technology (Hammerle, et al. 2009). The continuous technological progress in both the computer-based development and the dental fabrication process ensures new opportunities in the clinical workflow (Joda & Buser 2013).

Formerly, only one standard treatment approach was applicable: classical impression technique and physical gypsum casts for the manufacturing of acrylic- and porcelain-fused-to-metal reconstructions using the lost-wax-technique. Today, there are various paths open, and the team of clinician and dental technician has to choose how and when to proceed digitally: starting with the selection and timing of digitizing the patient's situation, following the choice of the implant reconstructive design and appropriate material components, the simulation and virtual pre-replication of esthetic appearance in demanding cases, up to economic calculations (Kapos & Evans 2014).

Manifold companies offer several devices, tools, and software applications, and consecutively, different workflow options may be confusing the clinician as well the dental technologist (Abduo & Lyons 2013, Miyazaki, et al. 2009). In addition, only a few systems are available with open workflows for step-wise selection of the obtained data sets (Kachalia & Geissberger , Wismeijer, et al. 2014). Overall, the purchase, installments, up-dates and maintenance as well as the implementation of new technologies are expensive, time-consuming and require operator’s patience for an individual learning curve (Holden & Karsh 2010, Joda & Bragger 2015, van der Zande, et al. 2013).

Therefore, the aim of this review is to highlight insights and anticipate future visions of digital technologies in fixed implant prosthodontics in order to develop a guideline for esthetics, economic aspects as well as possibilities and limitations in laboratory processing.

Digitization

BITS & BYTES

In industrial processing, benefits of computerized engineering technology are associated with high precision, simplified fabrication procedures and minimized manpower resources (Avery 2010, Dawood, et al. 2010). These advantages may also favor the digital workflow for quality assurance, accurate production and cost effective implementation in dental implant medicine (Fasbinder 2010, van Noort 2012).

The necessary step for virtualization is the prerequisite to digitize the individual patient situation – programmed in a binary code out of zero's & 'one's (Schoenbaum 2012). This digitization process transforming bits & bytes is applicable in two ways, labside and chairside scanning, respectively (Patel 2010). The labside pathway describes the classical impression technique with silicone or polyether impression materials and implant-specific transfer posts in combination with plaster master casts. Secondary, the build-up gypsum model situation has to be scanned with a laboratory scanning system. This approach still represents the goldstandard in the manufacturing process for fixed implant-supported reconstructions (Kapos, et al. 2009, Kapos & Evans 2014). On the other hand, the clinical situation can be registered digitally with a contact-free transfer using an intraoral optical scanner (IOS) system. In contrast to the conventionally labside pathway, IOS ensures the chairside digitization of the patient situation immediately in the oral cavity (Christensen 2009, Garg 2008).

Then, the scanning data, labside or chairside, is stored as standard tessellation language (STL) files (Abduo & Lyons 2013, Avery 2010). STL-files describe any surface geometry of three-dimensional (3D) objects by triangulation and can be used for computer-assisted-design and computer-assisted-manufacturing (cad/cam) of milled models, customized abutments and implant suprastructures (Joda & Bragger 2014, Priest 2005, Redmond 2001). [**Fig. 1**]

DIGITAL IMPRESSION

Implant impressions are influenced by multiple factors, including the type of technique, tray selection, used materials, and the inherent fit of components as well as the operator skill (Lee, et al. 2015, Papaspyridakos, et al. 2014). The use of IOS eliminates the need for traditional impression materials, and therefore, decreasing production failures from analog techniques (Eliasson & Ortorp 2012). For the production of small fixed implant-supported units, the digital protocol offers a streamlined and simplified workflow by means of quadrant-like IOS of the implant site as well as the opposite arch including occlusal registration within one operational approach (Joda & Bragger 2014). This capability reduces the potential of summation errors compared to the conventionally full-arch impression taking procedures in a multi-step approach.

In vitro investigations demonstrated a comparable level on accuracy, defined as precision + trueness, between classical impressions and different IOS systems for dentate full-arches (Ender & Mehl 2015, Seelbach, et al. 2013). However, it has to be stated that these results also indicate a strong dependency on the used system (Persson, et al. 2009, Ziegler 2009), the fit of the implant-specific scanbody and corresponding implant company provider (Stimmelmayr, et al. 2011), and on the personal training and skill of the clinical as well as technical operator (Andriessen, et al. 2014, van der Meer, et al. 2012). An additional success factor is the scanning strategy according to used IOS system (Ender & Mehl 2013).

PATIENTS' EXPECTATIONS

New technologies may not only provide advanced possibilities of functional rehabilitation, but also change the patients' attitude due to a digitization trend in general (Layton & Walton 2011). Patients are accustomed to digital tools from their everyday life, such as smartphones, tablet-computers, and they are well informed about the various technical opportunities using health-care-related online platforms. Therefore, the patients' mindset on dental implant therapy has continuously changed over the last years (Pommer, et al. 2011, Pommer, et al. 2011).

Patients assume functional and esthetic treatment results with implant-supported reconstructions. In fact, their expectations are even higher compared to conventional prosthetic rehabilitation concepts (Buch, et al. 2002, Tepper, et al. 2003). The patients' demands are also addressed to more comfortable treatment protocols. These include shortened treatment sessions combined with a condensed overall therapy as well as convenience-oriented appointments without affecting their personal schedules (Layton & Walton 2011, Nkenke, et al. 2007).

With the implementation of IOS, patients are prevented from harm during classical impression taking procedures due to suffocation hazard, gagging, and taste irritation (Christensen 2009, Patel 2010). However, studies are mostly limited to dental implant survival and clinical/radiographically surrogate parameters (den Hartog, et al. 2008). In contrast, patient-centered outcomes of implant treatment protocols have been unattended for years and are only gradually integrated into clinical trials.

Recently published randomized controlled trials compared patient-related outcomes for digital versus conventional implant impressions (Joda & Bragger 2015, Wismeijer, et al. 2014, Yuzbasioglu, et al. 2014). These clinical studies revealed consistent findings with an overall patients' preference significantly in favor of the IOS rather than the conventional technique for capturing the 3D implant position. Moreover, one pilot study evaluated the operators' perceptions comparing digital and conventional impressions in a standardized setting for single implant crowns (Lee & Gallucci 2012). Study participants were inexperienced undergraduate dental students performing both techniques on a phantom model. In this study, the digital protocol also resulted in higher operators' acceptance than the conventional procedure.
Overall, the digital workflow is significantly accepted as the most preferred implant impression procedure compared to the conventional technique according to the patients' perception and satisfaction. With regard to treatment comfort, the digital impression protocol with IOS is more patient-friendly than the conventional approach when it is performed by an experienced team of clinician and dental assistance (Joda & Bragger 2015, Wismeijer, Mans, van Genuchten & Reijers 2014, Yuzbasioglu, Kurt, Turunc & Bilir 2014).

Prosthetic Design

WORKFLOW

The ongoing development of information technology systems and their acceptance in social life has opened the opportunity to implement computer-based applications and fabrication techniques in dental medicine (Bauer & Brown 2001, Holden & Karsh 2010). In this context, 'digital dentistry' is a widespread (over-) used phrase. Prosthetic implant treatment seems to be and has to be entitled digital because it is en vogue. However, the truth in routine dental business reveals that there is seldom either the pure conventional pathway or a fully digital workflow (Kapos & Evans 2014) (Joda & Bragger 2016). Single digital work steps infiltrate the proven goldstandard, including classical impression-taking procedures, dental master cast fabrication, lost-wax-casting technique and individual finalization of the restoration with hand-layered veneering ceramics (Patel 2010). Changes are growing in the field of implant prosthetic treatment effecting IOS and cad/cam-production of frameworks. The result of this evolution is a mixed conventional-digital workflow (van Noort 2012).

Most benefits arise in the technical production. In fixed implant prosthodontics, reconstructions are not limited to the lost-wax-technique or milled frameworks with hand-layered veneering but also digitized veneering techniques with bonding or over-pressing techniques of cad/cam-milled occlusal surfaces to any kind of substructure are available or even full-contour restorations (Joda & Bragger 2014) (Joda & Bragger 2016). [**Fig 2**]

SINGLE-UNIT RECONSTRUCTIONS

A further development in the field of digital dental medicine is the treatment with monolithic crowns (Beuer, et al. 2012, Griffin 2013, Kim, et al. 2013). The overall treatment, starting clinically with an IOS, and following digital designing without any physical models, is simplified by having the option of connecting a fully anatomical crown to pre-fabricated abutments (Martinez-Rus, et al. 2013). Then, this entire workflow can be really entitled 'digital' within a complete setting of bits & bytes (Joda & Bragger 2016). Demanding laboratory work steps are streamlined and the material-specific advantages are ensured due to standardized fabrication quality (Joda, et al. 2015).

High-strength lithium-disilicate glass-ceramic (LS2) can be used as implant-supported restoration material for crowns with material properties demonstrating a flexural strength of 360 MPa. LS2 is processed with cad/cam-applications for monolithic reconstructions (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) (Guess, et al. 2010).

Initial laboratory investigations have demonstrated promising results (Joda, et al. 2015, Joda, et al. 2014). The results of the in vitro tests revealed constantly high values for stiffness and strength under quasi-static loading for pre-fabricated titanium abutments in combination with the bonded monolithic suprastructures. Monolithic implant crowns seem to represent a feasible and stable prosthetic construction under laboratory testing conditions with strength higher than the average occlusal force of naturally dentate patients (Joda, Burki, Bethge, Bragger & Zysset 2015, Joda, Huber, Burki, Zysset & Bragger 2014).

However, only a limited number of clinical trials are available at this time. The findings of a case series showed that fully anatomic implant-supported crowns seem to be a feasible treatment concept using a complete digital workflow. Partially quadrant-like IOS and cad/cam-technology in combination with pre-fabricated implant abutments demonstrated a shortened treatment in posterior sites (Joda & Bragger 2014).

In addition, the need for chairside corrections, such as secondary grinding and polishing, can be minimized or may not even be necessary within a complete digitized protocol (Joda, Katsoulis & Bragger 2015). This reduces work time but may also decrease the risk for cracks and chipping of veneer ceramics during maintenance (Joda & Bragger 2015, Joda & Bragger 2015). [**Fig 3**]

MULTI-UNIT RECONSTRUCTIONS

Two possible ways of fabrication are applicable for the treatment with implant-supported fixed dental prostheses (FDPs), a conventional and a mixed conventional-digital approach. Similar to single-units, both pathways normally use a technical concept of framework plus veneering technique (Avery 2010, Miyazaki, Hotta, Kunii, Kuriyama & Tamaki 2009).

In general, implant-supported FDPs can be divided in full-arch and short-span three- to four-unit reconstructions (Katsoulis, et al. 2015). The advantages of cad/cam-technology for the framework fabrication have been proven in laboratory settings for both FDP designs. The findings have consistently shown higher accuracy and precision in comparison of lost-wax-technique and digitally produced frameworks, whereas in case of full-arch multi-unit reconstructions the advantages are more present (Katsoulis, et al. 2014).

A mixed conventional-digital approach is widely used for the treatment of implant FDPs (Kapos & Evans 2014). The sequence can start clinically either with conventional impression-taking procedure or IOS. Nevertheless, a physical model situation with individualized mucosa mask is recommended using a gypsum model or a digitally produced one. Secondary, the physical models including the correct bite registration have to be digitized for further processing. Only the application of pre-fabricated abutments free of rotational limitations and the possibility to correct axial divergences ensures a simplified workflow for FDPs with rapid prototyping techniques. Finally, the dental technician can design the framework in a virtual environment with the dental technician's software. It is of advantage that a finalized occlusal relief can be simulated in order to create a uniformly reduced contour with proper space for the following veneering. [**Fig 4**]

A complete digital approach for the treatment with implant-supported FDPs seems to be technically feasible but has not been scientifically investigated yet. Therefore, it has to be seen as experimental at this current stage. The challenging aspect of fully digital processing of FDPs is the virtual definition of a functionally correct occlusion and further fabrication without any physical models. The dimensions of lacking antagonistic contacts impede a predictable and reliable digital bite registration. The clinical fitting and adjustments are the limiting factor, and consecutively, this will negate the originally digital advantages again (Joda, Katsoulis & Bragger 2015).

Besides the restrictions of the technical production, it is controversy discussed what type of restoration material would be suitable for monolithic FDPs. On the one hand, these materials have to withstand high loading forces, and on the other hand, an increased risk for abrasions may occur at the antagonists over time, especially in case of existing naturally tooth structures. In addition, the visual appearance of monolithic FDPs, regardless of the available materials, does not fulfill the expectations for the treatment in the esthetic zone.

Emergence Profile

ESTHETIC CONSIDERATIONS

The imitation of naturally look-alike implant-supported reconstructions still remains one of the major challenges in fixed prosthodontics (Cooper 2008). The white and pink esthetics of the final reconstruction and supra-implant mucosa has to mimic the previous tooth and match the adjacent dentition (Belser, et al. 2009, Furhauser, et al. 2005).

Bone level type implants are commonly used in the esthetic zone. A sub-crestal implant position is advantageous in order to deal with a higher amount of surrounding implant soft tissue. The prosthodontist has the opportunity to define the future crown margin, the final mucosal zenith and the emergence profile (Alani & Corson 2011); however, the clinical management of the consecutively prolonged trans-mucosal pathway becomes more challenging to create a harmonious and pleasant emergence profile (Joda, Ferrari, Bragger 2016). Subsequently, this bone level type implant concept may result in a change of term from *peri-implant* to *supra-implant* mucosa. [**Fig. 5**]

In general, dental implants and their prosthetic components differ from natural teeth in size and shape at the crestal bone and the mucosa level. When removing pre-fabricated healing abutments in the transition zone, the geometry of the mucosal profile is circular and does not match that one around natural triangular teeth (Chee 2003).

DIGITAL EMERGENCE PROFILE

Two classical approaches can be chosen for the finalization of the implant emergence profile: ‘immediate formation’ with the definitive implant reconstruction or ‘sequential formation’ with step-wise modifications of a fixed implant-supported provisional crown combined with a customized transfer of the individually shaped soft tissue architecture and secondary insertion of the definitive reconstruction (Buskin & Salinas 1998, Priest 2005).

The immediate formation is characterized by its simplicity and speed but reflects only a vague assumption mostly determined by the dental technician. Increased esthetic and functional risks for inadequate mucosa architecture due to uncontrolled pressure application are involved (Santosa 2007). The sequential formation with prior emergence profile modulation is very predictable (Chee 2003). But it has to be mentioned in particular that additional time-consuming appointments for modification of the implant provisional crown are necessary (Wittneben, Bragger, Buser, Joda 2016), and possible biologic trauma of the fragile implant soft tissue may occur due to repeated changes of the implant provisional (Lindhe & Berglundh 1998).

Is immediate placement of the final implant crown dental reality and daily life; and, is sequential mucosa conditioning with fixed implant provisionals just a sophisticated academic goldstandard? It will be of great benefit if it is possible to combine both techniques' advantages to presume the desired emergence profile fast, safe, and predictable in advance of the overall treatment.

It remains still a problem to capture visually the final emergence profile due to the prolonged trans-mucosal pathway. In addition to the possible limitation of the depth of focus of the used IOS device, a time-dependent shrinkage of the supra-implant mucosa architecture complicates the optical impression technique (Joda 2015). Hence, the individual modification of the implant-specific scanbody according to the shape of the implant provisional can be used for predictable emergence profile transfer (Joda, et al. 2014).

Digital dental processing ensures to fabricate individualized implant components with ideal soft tissue maintenance in combination with high-performance restoration materials (Joda, Ferrari, Bragger 2016). The application of a cad/cam-produced prosthetic component with an individualized shape, as a contour copy of the lost tooth, as a direct scan or mirrored image, offers a simplified as well as predictable approach in esthetic demanding cases. Besides the economic advantages of this streamlined workflow, biological compromises by means of repeating destruction of the epithelium attachment can be avoided. Furthermore, poorly polished acrylic surfaces of the implant provisional due to the multiple chairside adjustments may no longer be needed (Wittneben, Bragger, Buser, Joda 2016). [**Fig. 6**]

Digital applications have to be seen as additional tools. Esthetic demanding cases often need a 3D radiographic diagnosis. Then, this information should not be limited to the surgical treatment but can be also used for the desired soft tissue architecture. An actual cone beam computed tomography (CBCT) is not compellingly necessary. Any existing DICOM-data of the patient can be used for radiographic tooth-segmentation and 'copy & paste' contouring for the formation of the final emergence profile. With the help of the digital contour of the existing teeth (either the one to be replaced or the contra-lateral), there is no need for uncertain assumption of the prospective emergence profile. It is even easier if the shape information of the tooth to be replaced is accessible because mirroring is not required (Joda, Ferrari, Bragger 2016).

The supra-implant mucosa architecture can be individually created according to the digitalization of the contour of the extracted tooth or by the 3D radiographic shape of the mirrored contra-lateral for single-step emergence profile formation. The clinician's choice which approach to use mainly depends on considerations of patient-specific needs, the quantity and quality of supra-implant mucosa, as well as the availability and access to digital technologies and the gathered knowledge and skills of the dental team.

Economics

TIME-EFFICIENCY & COST ANALYSIS

Implant-supported crowns are the treatment of choice for the prosthetic rehabilitation of short-spam edentulous spaces (Abduo & Lyons 2013, Avery 2010). However, the implant-based treatment represents a more time- and cost-intensive solution compared to conventionally tooth-supported FDPs (Bouchard, et al. 2009, Braegger 2005). Therefore, it is of great interest to offer the advantages of implant dentistry to a broader population. Thus, it is only possible if new technologies are affordable which can shorten the overall clinical treatment and technical production time to achieve a reasonable cost-benefit ratio in combination with a high quality outcome of the final prosthetic reconstruction (Bassi, et al. 2013, Eaddy, et al. 2012).

A recent randomized controlled trial aimed to analyze time-efficiency of a treatment with implant crowns made of monolithic lithium-disilicate (LS2) versus porcelain-fuse-zirconium-dioxide (ZrO_2) in a digital workflow (Joda & Bragger 2016). Twenty participants were included for single-tooth replacement in posterior sites. The 3D implant position was captured with IOS. After randomization, ten patients were restored with monolithic LS2-crowns bonded to pre-fabricated titanium abutments without any physical models, and ten with cad/cam-fabricated ZrO_2-suprastructures and hand-layered ceramic veneering with milled master models. Every single clinical and laboratory work step was timed in minutes, and then analyzed for time-efficiency. Two clinical appointments were necessary for IOS plus seating of the implant crowns. The mean total production time, as the sum of clinical plus laboratory work steps, was significantly different, resulting in 75.3 min (SD ± 2.1) for digital, and 156.6 min (SD ± 4.6) for conventional workflows [$P = 0.0001$]. Analysis for clinical treatment sessions showed a significantly shorter mean chair-time for the complete digital workflow [$P = 0.001$]. Even more obvious were the results for the mean laboratory work time with a significant reduction of 54.5 min (SD ± 4.9) versus 132.5 min (SD ± 8.7), respectively [$P = 0.0001$] (Joda & Bragger 2016).

Besides time-efficiency, capturing cost parameters is crucial for decision-making of any therapy and is assumed to be of compelling interest to patients, health care providers, third party systems, and society in general (Walton & Layton 2012). Differences between service delivery systems, such as a university environment or a private practice setting, and the variability of treatment approaches combined with patient-centred factors have to be taken into account. Moreover, international properties with dissimilar health care systems, purchasing power, cultural, generational and gender differences markedly impede the impact of outcomes (Pennington, et al. 2009, Russell, et al. 1996).

Cost analysis determining economic efficiency for implant-supported reconstructions is still rare in the dental literature. Nonetheless, it is important to consider economic calculations in the context of clinical state-of-the-art treatment and when introducing new technologies (Bassi, Carr, Chang, Estafanous, Garrett, Happonen, Koka, Laine, Osswald, Reintsema, Rieger, Roumanas, Salinas, Stanford & Wolfaardt 2013, Holden & Karsh 2010).

A recently published economic process investigation with crossover design, calculations of direct costs, productivity rates and cost-minimization evaluated digital and conventional workflows of single implant crowns (Joda & Bragger 2015). These findings demonstrated a significant superiority of the digital workflow over the conventional pathway with classical impression-taking procedures and master plaster casts. In summary, digitally fabricated implant-supported single-unit reconstructions were 18% less costly for the entire clinical and laboratory treatment process than conventionally manufactured implant crowns (Joda & Bragger 2015).

Per definition, cost-benefit analyses (CBA) compare the costs expended on a specific treatment with the benefits obtained for that therapy. Both initial costs as well as maintenance costs are taken into account for analysis. This type of economic model requires strong prior evidence for long-term calculation (Bassi, Carr, Chang, Estafanous, Garrett, Happonen, Koka, Laine, Osswald, Reintsema, Rieger, Roumanas, Salinas, Stanford & Wolfaardt 2013). CBA can only be estimated based on the findings in the scientific literature. The Proceedings of the 5th ITI Consensus Conference reported on treatment guidelines and recommendations for restorative materials and techniques for implant dentistry. Here, it was concluded that cad/cam-generated abutments, crowns and frameworks demonstrate survival rates comparable to conventionally fabricated implant prostheses (Kapos & Evans 2014). Due to this current knowledge, it can only be assumed that CBA in a long-term observation would also be comparable for digital and conventional workflows.

The purchase of long-lasting equipment is a supplementary factor to be considered in cost analysis. The needed clinical equipment for capturing the 3D implant position differs for both workflows. The digital workflow requires the purchase of an IOS device, subsequent software updates, and maintenance costs. On the other hand, diverse trays in different sizes, impression materials and corresponding mixing machines are necessary for the classical impression-taking procedure. The comparison of digital and conventional equipment costs is much more complex due to the fact that both IOS and classical impression-procedures are commonly used in daily dental routine for several treatment procedures, such as tooth-retained restorations and implant-supported reconstructions in the fields of fixed and removable prostheses. Therefore, an overall cost separation is difficult to perform (Walton & Layton 2012).

The digital workflow seems to be more efficient than the well-established conventional pathway. For the patient´s value, cost-minimization analysis exhibited less overall treatment costs including laboratory rates for implant crowns manufactured with IOS plus cad/cam-technology. In addition, the digital workflow seems to be more profitable for the dentist due to higher productivity rates and shortens the prosthetic treatment to achieve a reasonable cost-benefit ratio.

Future Perspectives

PROCESSING

Upcoming trends in reconstructive dentistry will focus on developments in rapid prototyping production. Hence, the technological progress is split in subtractive methods, as milling with multi-axes machines or promising new approaches as laser ablation, and additive processing, as 3D printing and selective laser melting, respectively (Torabi, et al. 2015). [**Fig. 8**]

The standard in the field of computerized dental fabrication is undeniably the milling technology. Even though, the quality of the devices continuously increased over time, the limitation of milling devices is still the diameter of the used drills (Touchstone, et al. 2010). This might be eliminated with the laser ablation technique in future. Despite of that, the additive creation of 3D objects is more sustained compared to the subtractive techniques from an ecological point of view. Classical cad/cam-subtractive procedures using commercial blanks for a single-unit crown generate approximately 90% waste of fine particulates and only 10% are used for the reconstruction itself. In contrast, the additive way, make only use of the powder material what is really needed for the desired object. Moreover, additive processing ensures the realization of more complex geometries (Berman 2012).

Today, 3D printing is mostly used for provisional reconstructions and surgical implant guides. However, the fabrication of definitive crowns or FDPs is not feasible due to limited properties of the available materials in dental medicine (Stansbury & Idacavage 2016). Selective laser melting is widely used for cobalt-chromium and titanium frameworks. First published studies demonstrated comparable results in fixed reconstructions out of gold-alloy frameworks, and even superior results for reduced- and non-gold-alloy frames produced with the lost wax-technique, respectively (Huang, et al. 2015).

SUPERIMPOSITION

Digital technology approximates the interface of prosthetic and surgical implant treatment: from the virtual planning, plotted on a guidance template, to the cad/cam-based design, including production of the final prosthetic reconstruction. A prerequisite is the superimposition technique of CBCT-generated DICOM-data and STL-files obtained from IOS (Joda & Buser 2013).

Supplementary technologies for facial and dental imaging have to be considered for the creation of 3D virtual patient simulation (van Noort 2012). The output of research projects investigating virtual technologies has been continuously increased over recent times (van der Zande, Gorter & Wismeijer 2013).

However, the complexity remains to superimpose diverse tissue structures to a triad: facial skeleton (DICOM), extraoral soft tissue (OBJ), and dentition including surrounding intraoral soft tissue (STL) (Joda & Gallucci 2015). Not only the unique anatomical structures are particular in nature but also the corresponding digital 3D data, obtained from radiology and scanning techniques, differ in their formal data structure (Plooij, et al. 2011).

The replication of a 3D virtual patient requires the successful fusion of these specific data formats. The matching process of the first method is based on corresponding landmarks, while the other two use congruent surfaces or voxels of manually selected regions (Swennen, et al. 2009).

How far are we in virtual dentistry? Today, none of the craniofacial imaging techniques are able to capture the complete triad with optimal quality in a single-step (Joda, et al. 2015).

In advanced implant prosthetic cases, a concentrated triad approach, limited to the anatomical regions of the mandible and the maxilla including the sinuses, could provide sufficient information for treatment planning. The patient would significantly benefit from the 3D model situation by means of analyzing anatomical structures and simulating prosthetic outcomes in advance. For example, a goal of future therapy planning should be the pre-treatment evaluation if an adequate lip support could be achieved in demanding esthetic-functional rehabilitation protocols of edentulous or partly dentate situations. Moreover, the amount of radiation exposure could be reduced because the field of interest for digitalization would have been scaled down (Joda, Bragger & Gallucci 2015).

It should be taken into account that the currently available fusion models have been investigated under university settings. At this stage, it takes more time to evaluate and validate the various methods before the fusion models will be routinely implemented in daily clinical practice. Moreover, validate accuracy tests have to be developed to compare the different superimposition techniques based on the 3D media files.

At the present time, investigations presented only 3D virtual simulations under static conditions. Dynamic actions of the jaws, lips and muscles in order to build a complete 4D replication of a human head, integrating skeleton, extra- and intraoral soft tissues as well as dentition, have not described by any study yet. Therefore, this seems to be a crucial step in the translational aspect of this technique to develop a 4D virtual patient in motion. Even though, it is still feasible to extract a single frame of 3D data from a captured 4D video sequence and export this for superimposition with CBCT data, however, no commercially available system is (yet) able to fuse a 4D sequence of mimic facial movements onto DICOM, OBJ, STL and/or any other 3D medical file format (Joda, Bragger & Gallucci 2015).

Conclusions & Recommendations

Protocols for single-unit monolithic implant crowns connected to pre-fabricated titanium abutments starting with IOS and combined with virtual design and production without any physical master casts have to be considered in place of conventional manufacturing. However, a complete digital approach for the treatment with implant-supported FDPs has not been scientifically investigated yet, and therefore, cannot be recommended for routine use at this time.

In this context, it should be mentioned that several digital dental systems offer different workflow protocols. Most of these systems were developed for a closed process. Results reporting on one specific workflow sequence may not be transferable to other ones.

Digital applications have to be seen as additional tools in complex and esthetic demanding cases. Individualized supra-implant soft tissue architecture can be calculated in advance according to morphologic shape of the extracted tooth itself or designed as a contour copy of the digitally flipped contra-lateral tooth.

Superimposition technology of computerized files, such as STL, DICOM, and OBJ, allows the simulation of the treatment outcome in advance. However, additional developments are required to evaluate and validate the various methods before these fusion models can be implemented in clinical practice.

In general, new treatment protocols have to be trained and learning curves also have to be considered while implementing digital dental workflows in daily routine. The correct indication and application are a prerequisite and crucial for the success of the overall therapy, and finally, for a satisfied patient. This includes a teamwork approach and equally affects the clinician, the dental assistance, and the technician as well.

Nowadays, it is not a question of ‘if’, more or less than ‘when’, to jump on the digitalization trend in implant dental medicine. Subsequently, this trend will change the entire dental profession. It has to be emphasized that further scientific validation on digital treatment is necessary to understand the impact of this promising technology for modifying well-established conventional protocols. Benefits will arise to reduce production costs, improve time-efficiency, and to satisfy patients’ perceptions of a modern treatment concept. Supplementary large-scale clinical studies including different digital systems are compellingly necessary for a better utilization of all possibilities and to understand the potential of the digital technology.

Acknowledgements

The authors express their gratitude to dental technician Thomas Furter (ArtDent, Bern, Switzerland) for the production of all presented cases in this review.

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Figures

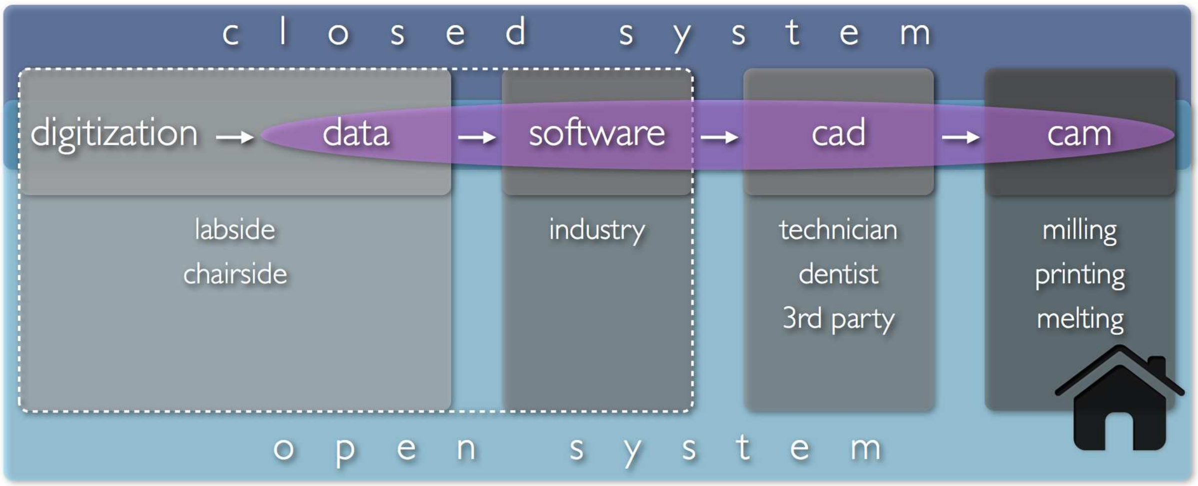


Fig. 1. Digital processing in implant prosthetic dentistry.

Figures

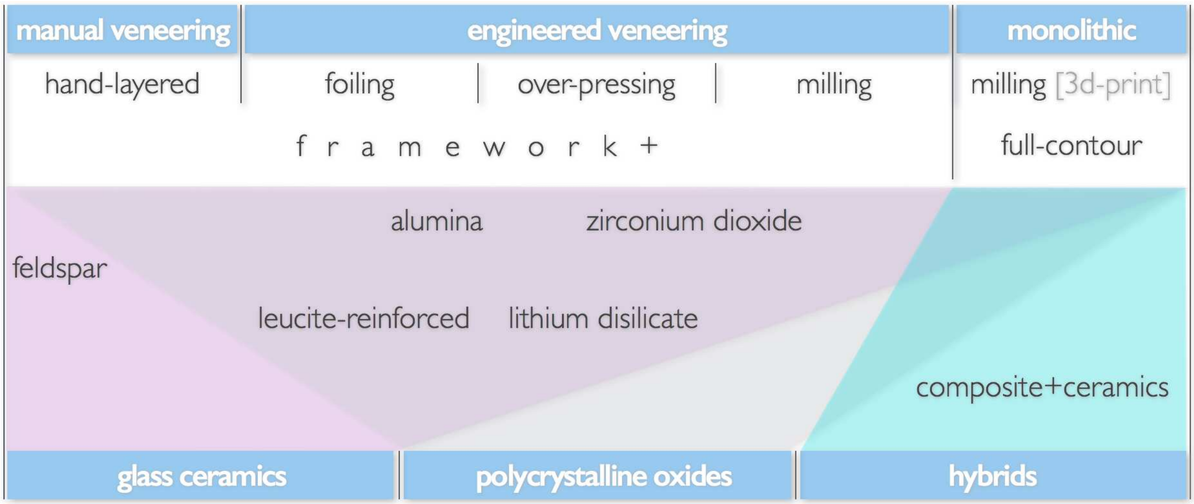


Fig. 2. Reconstructive design and dental material solutions corresponding to the production technique.

Figures

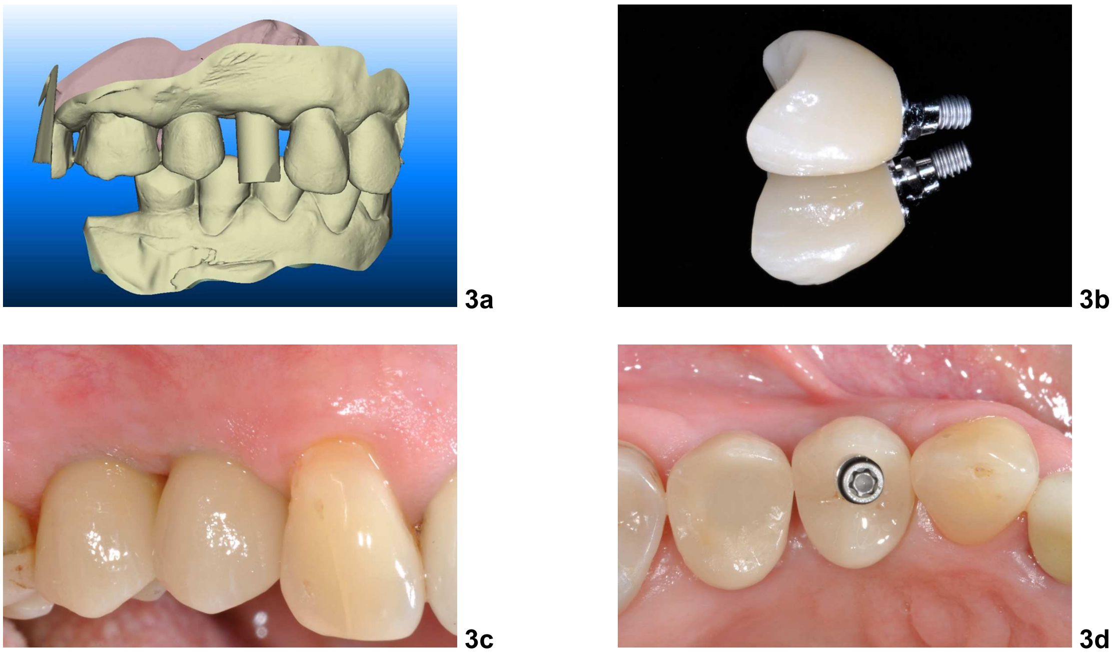


Fig. 3. Complete digital workflow for the treatment with a monolithic implant-supported single-unit crown: **3a**. intraoral scanning (IOS) as pre-operational step for virtual designing; **3b**. finalized implant reconstruction out of pre-fabricated titanium abutment plus full-contoured lithium-disilicate (LS2) crown; **3c+d**. clinical situation with inserted LS2-reconstruction.

Figures

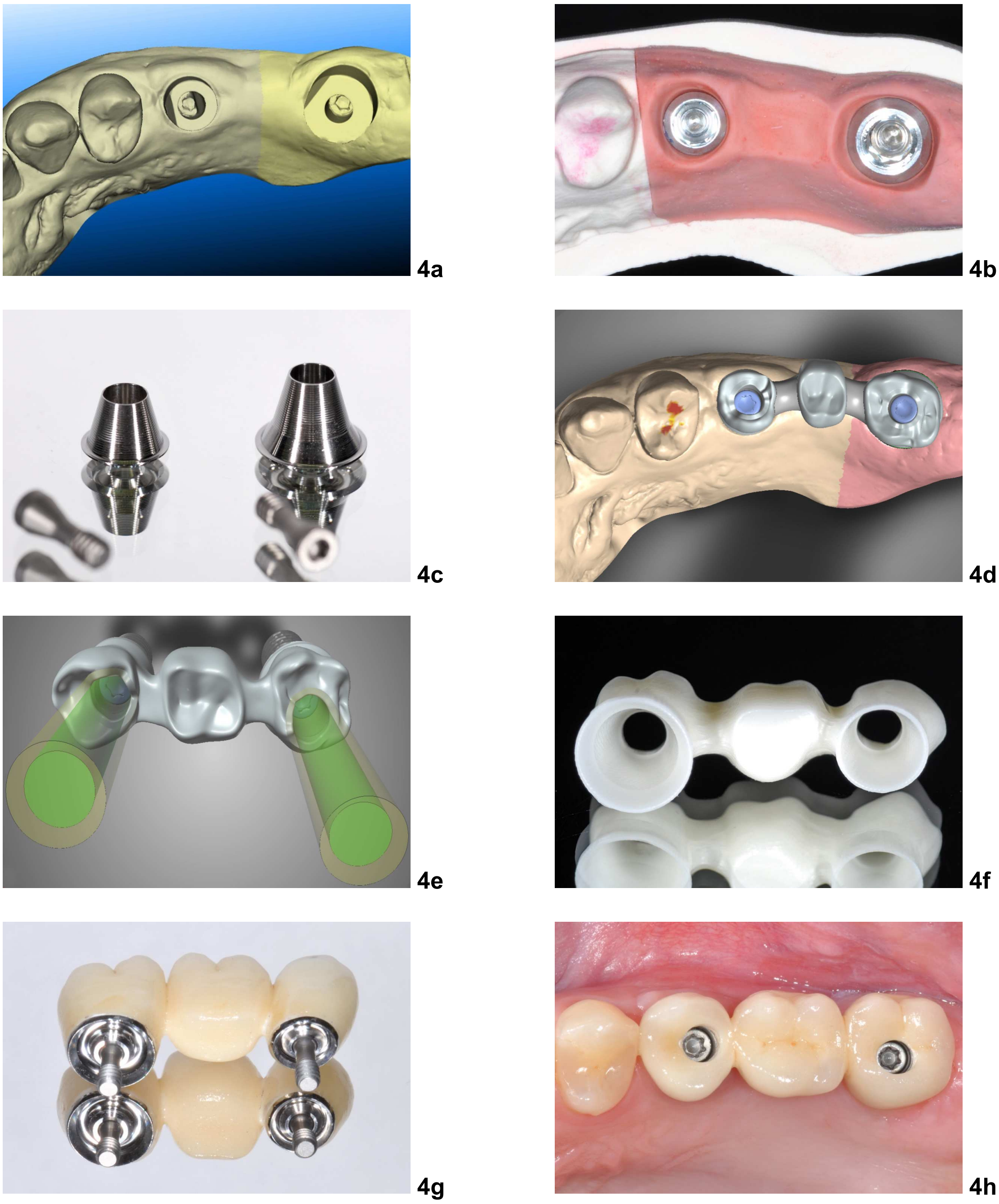


Fig. 4. Mixed conventional-digital workflow for the treatment with a implant-supported three-unit fixed dental prosthesis (FDP): **4a.** intraoral scanning (IOS); **4b.** milled model situation with individualized mucosa mask; **4c.** pre-fabricated titanium abutments with special design for FDP-indication; **4d+e.** virtual design of a screw-retained FDP; **4f.** cad/cam-produced zirconium-dioxide (ZrO_2) framework; **4g.** finalized implant reconstruction with manually ceramic veneering and bonded titanium abutments; **4h.** clinical situation with inserted implant-supported screw-retained FDP.

Figures

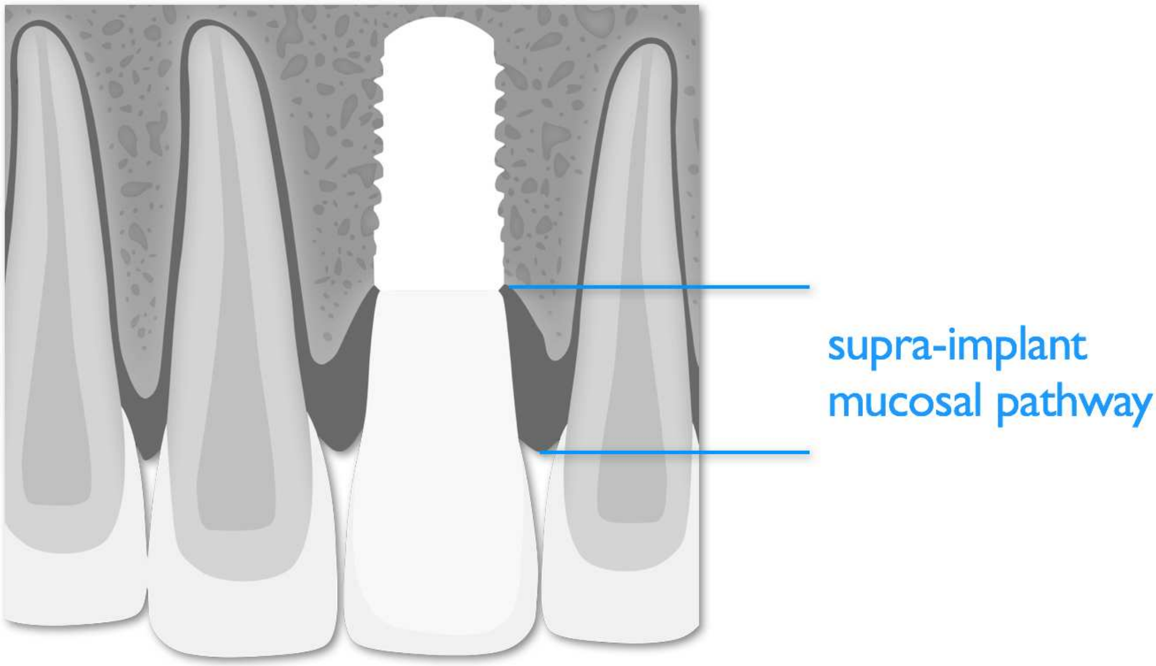
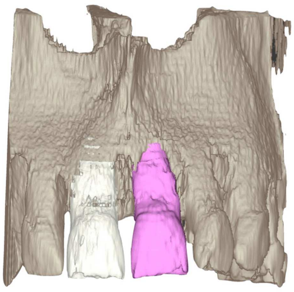
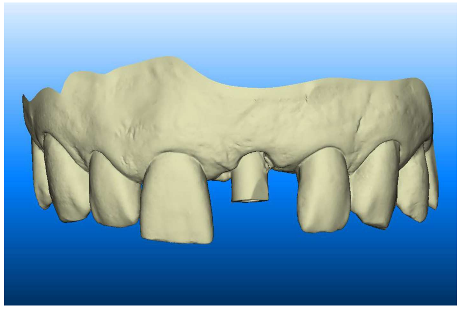


Fig. 5. The use of bone level type implants with sub-crestal 3D positioning requires a re-thinking of the implant prosthetic concept in the esthetic zone due to a prolonged trans-mucosal pathway; and therefore, the term *peri-implant* mucosa should be changed into *supra-implant* mucosa.

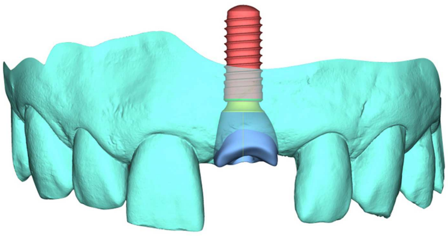
Figures



6a



6b



6c

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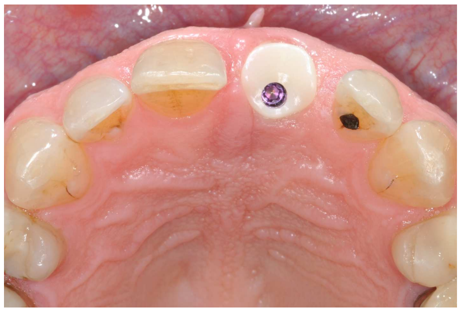

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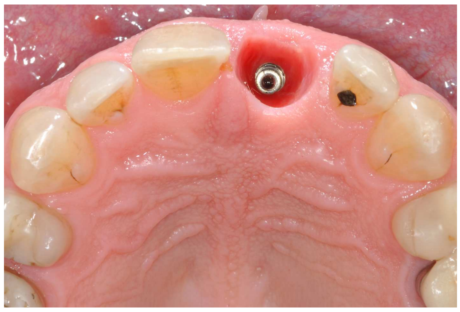

6h

Fig. 6. The mirrored-salami-technique (MST) for 1-step formation of the supra-implant emergence profile: **6a.** maxilla DICOM-data with segmented natural tooth 11 [white] and mirrored copy for visualization of the prospective emergence profile of the implant reconstruction in position 21 [pink]; **6b.** screenshot of the STL-file gathered from a digital impression with screwed scanbody for detection of the final implant location; **6c.** three-dimensional imaging of the individualized healing abutment on top of the virtual implant in position 21; **6d.** pre-fabricated titanium bonding base plus cad/cam-abutment before luting (Variobase + Polycon ae, CARES Digital Solutions, Institut Straumann AG, Basel, Switzerland); **6e+f.** clinical situation with individualized healing abutment according to the mirrored DICOM-based contour of the contra-lateral tooth 11; **6g+h.** modulated final emergence profile four days after placement.

Figures

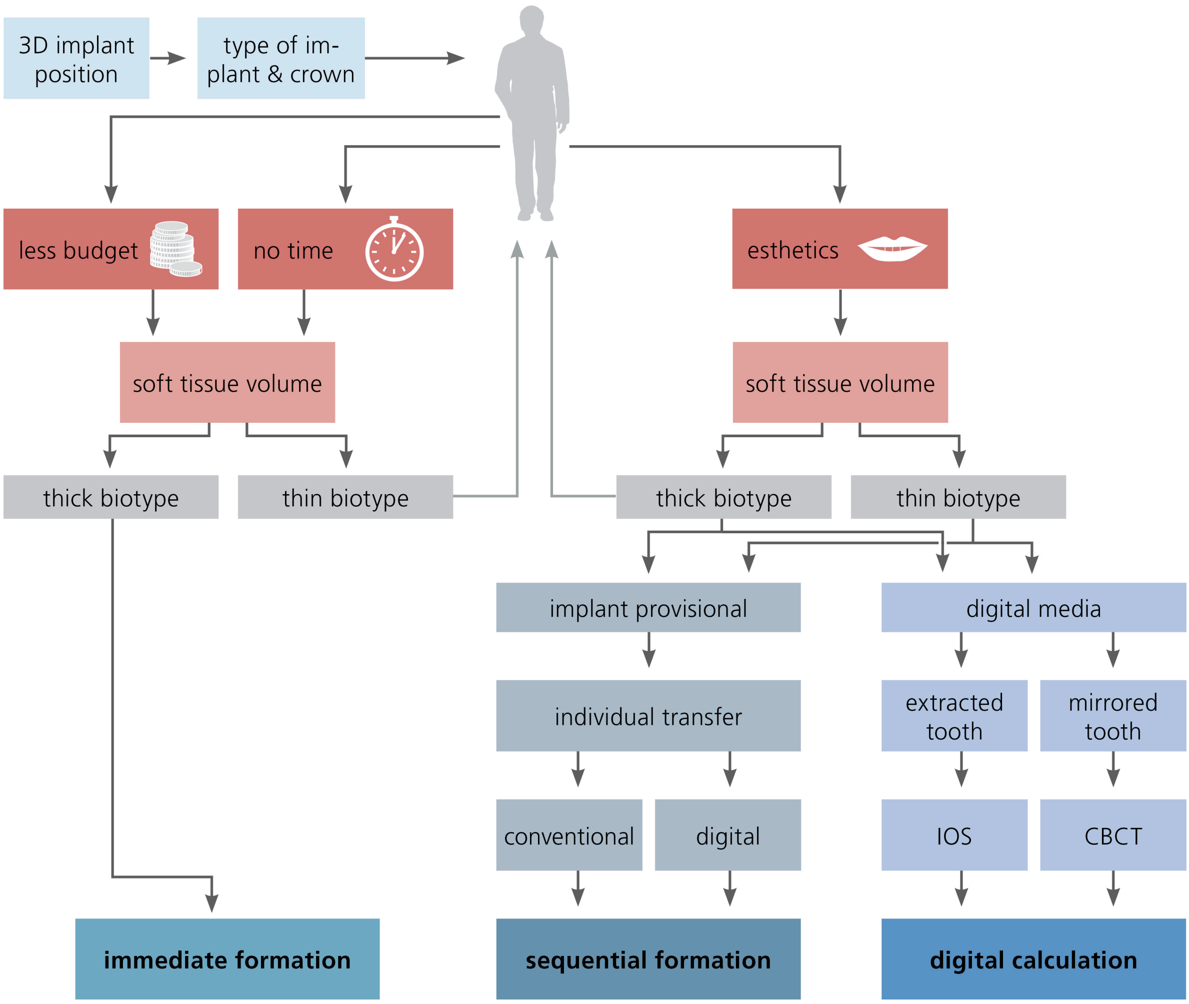

Fig. 7. Flow-chart describing a decision-tree for patient-selective pathways in case of supra-implant emergence profile formation under consideration of esthetic demands, economic factors (as time and budget), soft tissue conditions, and access to digital media.
[IOS = intraoral optical scan | CBCT = cone beam computed tomography]

Figures

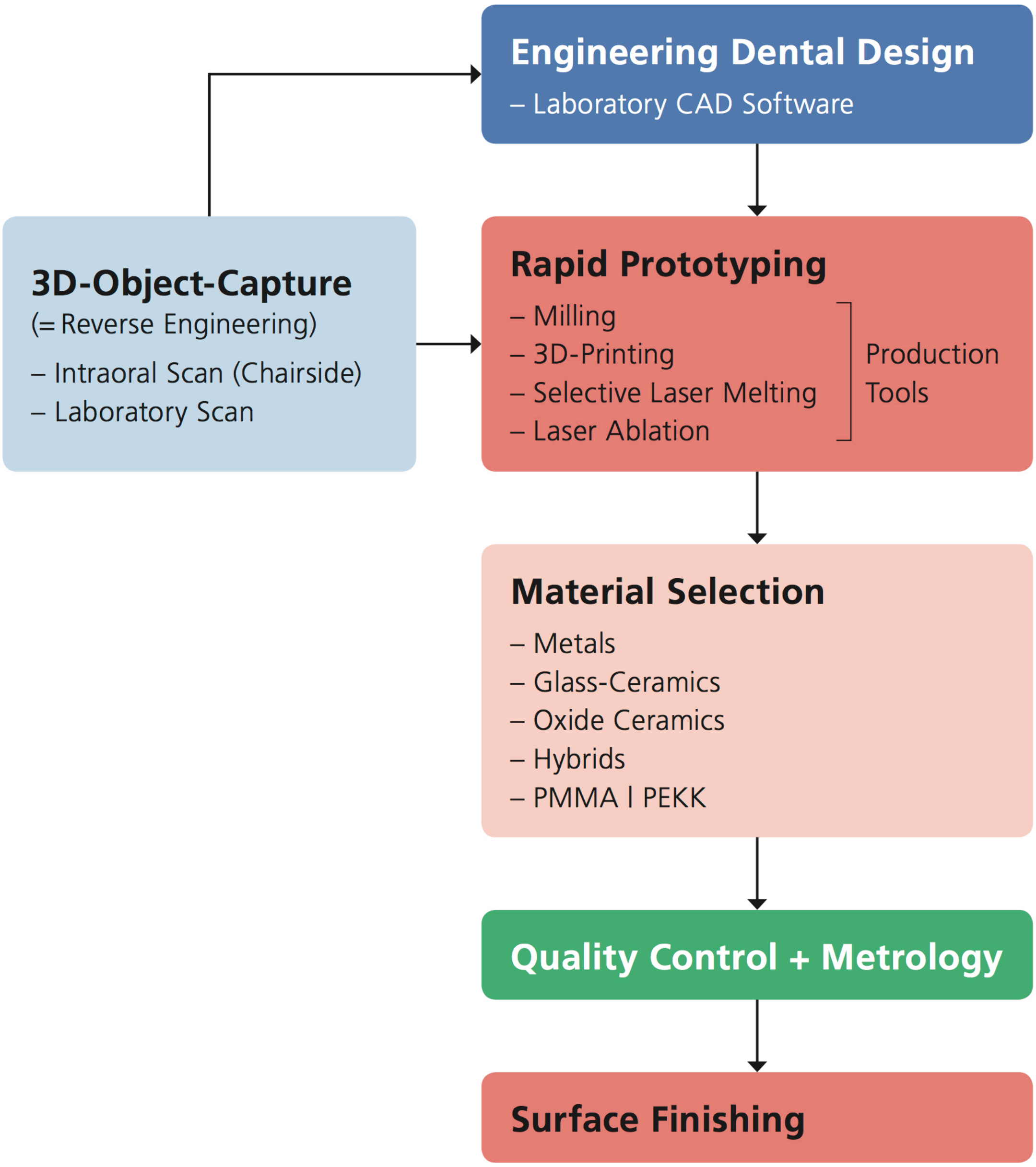

Fig. 8. Flow-chart depicting the process of rapid prototyping.
[PMMA = Poly (methyl methacrylate) | PEKK = Polyetherketoneketone]