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Key words: CAD/CAM, computer, digital technologies

Abstract
Objective: The task of this working group was to assess the existing knowledge in computer-assisted implant planning and placement, fabrication of reconstructions applying computers compared to traditional fabrication, and assessments of treatment outcomes using novel imaging techniques.

Material and methods: Three reviews were available for assessing the current literature and provided the basis for the discussions and the consensus report. One review dealt with the use of computers to plan implant therapy and to place implants in partially and fully edentulous patients. A second one focused on novel techniques and methods to assess treatment outcomes and the third compared CAD/CAM-fabricated reconstructions to conventionally fabricated ones.

Results: The consensus statements, the clinical recommendations, and the implications for research, all of them after approval by the plenum of the consensus conference, are described in this article. The three articles by Vercruysen et al., Patzelt & Kohal, and Benic et al. are presented separately as part of the supplement of this consensus conference.

Date:
Accepted 18 May 2015

To cite this article:

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During the past years, digital technologies have become of increasing importance in clinical dentistry including implant dentistry. Computers may help improve patient treatment in various ways and at different time points during therapy. New technologies allow obtaining patient data in ways other than traditional recordings. These predominately encompass intra- and extra-oral surface scanning and radiographic capturing of craniofacial hard structures. Furthermore, a number of additional methods are being developed and tested for their use in the clinic. These data may then be processed applying digital techniques providing the clinician with novel ways to integrate and interpret relevant patient data. On the one hand, this improves diagnosis of the state of health or disease of the patient, and on the other hand, working with these digital data supports planning and execution of the different steps of treatment. Taken together, this renders implementation of the planned treatment more precise and predictable. In addition, computer technologies help improve the quality of the final reconstructions. In particular, computers enhance the control over the design of the provisional and final reconstructions and they provide the possibility to manufacture dental reconstructions using industrially controlled fabrication processes. These processes are ideally performed under higher standards of quality and predictability than traditional ones. Finally, novel technologies may help assessing treatment outcomes more precisely and more economically and thus provide new knowledge for choosing optimal therapeutic methods and pathways. With these new possibilities in mind, groups of researchers were given the task to assess the state of the science in computer-supported diagnosis, fabrication and assessment processes focusing on the following three specific topics: Vercruyssen M, Laleman I, Jacobs R, Quirynen M. Computer-supported implant planning and guided surgery: a narrative review (Vercruyssen et al. 2015).

Patzelt SBM, Kohal RJ. CAD/CAM-fabricated implant-supported restorations: a systematic review (Patzelt & Kohal 2015).

Benic GI, Elmasry M, Hammerle CHF. Novel digital imaging methods to assess the outcome of implant therapy: a narrative review (Benic et al. 2015).

Based on the content of these reviews, the respective topics were thoroughly discussed among the group participants and the reviews were amended, if considered necessary. Thereafter, the group developed consensus statements on these topics, clinical recommendations, and implications for research. These were then presented to the plenum of the consensus conference, where they were discussed and approved. Note that digital technologies are a very dynamic area in implant dentistry and, hence, it may soon become necessary to review the literature again to summarize changes and developments.

Computer-supported implant planning and guided surgery

Major findings from the review

Currently, different computer-supported systems are available to optimize and facilitate implant surgery. Due to the fact that there is little evidence available for the dynamic approach (navigation), the focus in this text is on static systems (surgical guides).

Guided implant surgery clearly reduces the inaccuracy as compared to free-hand surgery, defined as the deviation between the planned and the final position of the implant in the mouth. It may be recommended for the following clinical indications: complex anatomy, need for minimal invasive surgery, optimization of implant placement (e.g., critical esthetic cases), and immediate loading.

The transfer of the implant planning data using a suitable software program to the operative field remains the most difficult part. Digital technology rapidly evolves and new developments will enable further improvements in reducing the inaccuracy. A crucial approach includes the reduction of the number of steps needed from the preoperative examination of the patient to the actual execution of the guided surgery. The implementation of optical scans combined with 3D radiological data and 3D printing will make this possible. If the predictability of the treatment can be increased, the number of clinical indications can also be further expanded.

Consensus statements

Indications for guided surgery may include the following: the need for minimally invasive surgery or flapless approach, optimization of implant planning and positioning, and immediate reconstruction.

General aspects

A cumulative deviation error may occur during the multiple phases of the procedure, for example, by the cross-sectional imaging scan, the image segmentation, the virtual planning, the fabrication of the guide, the positioning of the guide, and the surgical procedure itself.
Using guided surgery, deviation from the planned position varies among different studies, some reporting large variations. This has to be taken into account, when following these procedures to prevent the unintentional damaging of anatomical structures.

No overall differences were observed for the accuracy of guided surgery in the mandible compared to the maxilla. The accuracy obtained when following guided implant surgery protocols increases the possibility to deliver an ideal final reconstruction.

Surgical guides

Surgical guides may be supported either by mucosa, teeth, bone or (temporary) implants. In all these situations, additional stabilization may be obtained by bone-retained screws or pins. Tooth support of the surgical guide renders the highest accuracy of the procedure. Mucosa-supported guided surgery procedures offer higher accuracy than bone-supported procedures. When temporary implants are available, stabilization of the scanning prosthesis and the surgical guide on the same pre-installed (temporary) implants leads to more accurate surgical procedures.

Surgical guides can be fabricated conventionally or with rapid prototyping techniques.

Osteotomy and implant placement

In addition to inaccuracies resulting from imprecisions between planning and execution as well as from imprecisions of guide placement, a certain tolerance exists between the drills and the sleeves. This tolerance varies among different systems and leads to different amounts of inaccuracies. After a fully guided osteotomy, guided implant insertion shows higher accuracy than free-hand placement.

Reconstructive aspects

Guided implant placement facilitates the use of pre-fabricated CAD/CAM provisional or final restorations, which can be delivered immediately after implant placement.

Clinical recommendations

Planning should always be based on the need to achieve a prosthesis that respects the biological, functional, and esthetic requirements. As guided surgery may add precision to flapless surgery, it can have its implications in geriatric patients and in individuals with compromised medical conditions.

As the teeth on the scan prosthesis or the virtual setup are used as guide for the position of the future implants, a correct setup of the planned teeth is mandatory. The use of pre-installed fiducial markers can increase the accuracy of the scan prosthesis matching process in the planning software.

Cone-beam or conventional computed tomography is not always sufficiently accurate to create a tooth-supported guide. It is recommended to take an additional impression (either digitally or analog) of the remaining teeth, which is then matched with the radiographic images to create a more accurate 3D model of the teeth. CT does not offer advantages over CBCT regarding guided implant surgical procedures. The ALARA principle (radiation exposure “as low as reasonably achievable”) needs to be respected.

Changes in the alveolar bone and soft tissues during the time between (CB)CT and surgical intervention have to be taken into consideration.

Implications for research

The category of patients, who benefit the most from guided surgery, should be identified more clearly. Efficacy of these procedures needs to be further elucidated. Protocols involving the partial utilization of these technologies should be validated.

A possible stress reduction in the operating theater resulting from using computer-assisted planning and implant placement should also be analyzed.

Future research should aim at reducing the number of steps needed from the preoperative examination to the actual execution of the guided surgery. The possible errors occurring and their magnitude in each procedural step should further be investigated. Further studies need to define which deviations from planning to execution of computer-guided surgery are clinically acceptable.

Research should help identify the safety distances to be respected from vital anatomical structures when inserting dental implants. This is of importance as in the future planning and executing implant insertion using guided surgery will become more precise.

New techniques in this area need to be validated before they are introduced into the clinic.

The use of CAD/CAM methods versus conventional methods in reconstructive dental implant therapy

Major findings from the review

CAD/CAM-fabricated reconstructive components may encompass abutments, frameworks, and veneers. The scarce data identified within the present review (one study for single crowns, one study for partial FDPs, 10 studies for full-arch FDPs) reported cumulative survival rates (CSR) for abutments and frameworks ranging from 95% to 100%. The rather short observation periods of the studies ranged from 1 to 5 years.

Overall, the most frequent complication encountered was chipping of ceramic veneers and resin veneers. For the full-arch FDPs, three titanium framework fractures were reported. In addition, one ceramic abutment fracture was observed in a single crown site.

Overall, the number of studies, the amount of patients included, the patients available for follow-up examinations, and the short observation period of the majority of the studies do not allow making sound clinical recommendations.

Consensus statements

Digital technology for the design and manufacture of implant prosthetic components is used for abutments, crown and bridge frameworks, and associated veneers. For some of the components – abutments and frameworks – clinical feasibility has been demonstrated. Short-term studies demonstrate promising results. Long-term clinical studies, however, on CAD/CAM implant reconstructions are lacking.

No information is presently available on implant reconstructions entirely made with CAD/CAM procedures, either having all components – abutment, framework, and veneer – made separately, or two or all of them made in one piece (monolithic).

The systematic review reported on failures and technical complications of CAD/CAM-fabricated reconstructions including chipping of veneers, fracture of frameworks, and abutments. It is important to realize that conventionally fabricated reconstructions are also subjected to these types of failures and technical complications. A possible magnitude of difference regarding failures and technical complications between CAD/CAM and conventionally fabricated reconstructions can presently not be derived from the literature available.

Clinical recommendations

Digital technology can provide technical, clinical, and procedural benefits. Clinicians should be aware of the lack of appropriate clinical documentation to widely apply the use of the CAD/CAM implant reconstructions.

Computer-aided reconstructive dentistry can be applied in situations, where specific
benefits over conventional pathways are anticipated regarding:
- Data acquisition, management, and storage
- Standardization of data and procedures
- Communication tools
- Industrialized fabrication of components
- Possibility of processing new materials
- Reduction of time and efforts
- Reduction of costs

Implications for research
The introduction of CAD/CAM technologies and their rapid development has added a multitude of new parameters to be tested in clinical trials and thereby increased the complexity of research. It is becoming progressively more demanding for the researchers to identify the most relevant clinical questions and the appropriate control groups.

Patient-reported outcome measures (PROMs) should be the main endpoint of clinical trials in this field, and the research should not be driven by the new technological parameters.

For the validation of the CAD/CAM technologies, assessments of clinical outcomes should be performed such as prosthesis survival, esthetic, technical, and biological parameters, as well as efficacy, effectiveness and efficiency (e.g., cost/benefit ratio).

In order to be able to draw reliable conclusions cohort studies, controlled studies and randomized controlled studies are needed including large numbers of patients and reconstructions with long-term observation periods.

In this rapidly evolving field, a standardization of terminology is urgently needed to improve communication. A clear description of the procedures and tools applied as well as the use of generic instead of product specific terms is highly desirable. Finally, proper indexing of the published studies is needed to ensure that they can reliably be identified.

Novel digital imaging techniques to assess outcomes in oral rehabilitation with dental implants

Major findings from the review
The health of the peri-implant tissues and functional aspects related to the implant-supported reconstruction are important parameters, when considering outcomes of oral rehabilitation with dental implants. Moreover, the visual appearance of the peri-implant soft tissues and the restorations with reference to the existing dentition and the facial frame is essential for clinical success in esthetic sites. In the postoperative assessment of bone augmentation procedures, an evaluation of the stability of bone morphology is a basic requirement.

Recent technological progress has provided useful tools for assessing outcomes of oral rehabilitation with dental implant including the following techniques: cone-beam computed tomography, magnetic resonance imaging, ultrasonography, optical scanning, spectrophotometry. Whereas some of these tools, for example, cone-beam computed tomography, are already quite well established and frequently applied, more recent devices have not yet been evaluated with respect to the clinical benefits resulting from their use.

Consensus statements
Digital imaging techniques combined with dedicated software allow objective and standardized postoperative follow-up of implant-related parameters. These are as follows:
- Peri-implant bone volume, morphology, and trabecular structure
- Morphology and the color of the mucosa
- 3D implant position
- Contour and the color of the reconstruction
- Extent of the prosthetic misfit

Different imaging techniques using ionizing or non-ionizing radiation can be used for these postoperative assessments.

Cone-beam computed tomography
Postoperative imaging of dental implants by means of CBCT cannot be justified in the absence of a direct benefit for the patient except as part of ethically approved clinical research. Cross-sectional imaging may be helpful for the diagnosis and management of complications, such as nerve damage or postoperative infections [EAO guidelines – Harris et al. 2012].

In clinical research, CBCT is increasingly being used for 3D assessment of bone and soft tissue following augmentation procedures and implant placement.

Artifacts can have a considerable effect on the diagnostic image quality. Currently, there are no effective methods for the reduction of artifacts around dental implants in CBCT.

Magnetic resonance imaging
Magnetic resonance imaging (MRI), a non-ionizing radiation imaging technique, can be used to depict soft tissues. In high-resolution mode, it allows visualizing nerves and vessels.

Optical scanning
To assess treatment outcomes, optical scanning is increasingly being applied for the 3D assessment of the changes to the soft tissue contours particularly in the esthetic zone.

The combination of an optical scan with a preoperative CBCT can be applied postoperatively for the determination of the 3D implant position in relation to the planning and neighboring anatomical structures.

Optical scanners may also represent an efficient clinical method for the accurate quantitative assessment of the extent of the misfit between the reconstructions and the implants.

Spectrophotometry
Spectrophotometry is being used to objectively assess color differences in dentistry.

The objective of this technique is to compare the optical properties of the restorative materials and the marginal mucosa to the natural dentition.

New developments in this field, such as spectroscopy and hyperspectral imaging, may represent possible approaches for monitoring peri-implant soft tissue health and disease.

Clinical recommendations
Clinicians should follow the recommendations made in the European Commission Council Directive (1997) for the use of ionizing techniques in dentistry. This directive deals with the health protection of individuals against the dangers of ionizing radiation used for medical purposes. It also states that the principle of justification requires that the use of optional techniques associated with less or no exposure to radiation should be taken into account.

Currently, most of the novel digital imaging techniques have not been sufficiently validated for outcome measures and, therefore, should not be used for this purpose in clinical practice. It seems unlikely that in the near future MRI, ultrasonography, and optical coherence tomography will be implemented in clinical practice considering the limited
availability, the cost, and the need for specialized training.
When available, multiple patient-related data sets (e.g., CBCT, intraoral and laboratory scans, virtual planning of implants and restorations) should ideally be integrated to maximize their synergistic diagnostic value. This procedure can also be used to virtually visualize specific patient outcomes. This can be helpful in exploring patient’s expectations and providing information regarding limitations to the clinical outcome.

To allow exchange and integration of various data sets, clinicians should preferably use devices and software applications that offer fully compatible data transfer. Data protection regulations for different countries need to be considered. University and educational centers should provide specialized education and training in digital technology for all professionals involved.

Implications for research
Digitally acquired parameters of clinical outcomes should be related to patient-reported outcome measures (PROMs).

References

