CHAPTER 01: General introduction
Restorative dentists and technicians have been early adopters of innovation. In the 1970s, Duret adapted the concept of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) from the airplane industry and introduced the third dimension into digital dental treatment planning. In 1987, Mörman developed the first full chairside CAD/CAM workflow with the production of inlays and onlays under the name “Cerec” (Chairside Economical Restoration of Esthetic Ceramics, figure 1). Since then, more and more three-dimensional digital workflows have been developed, adapted, and implemented in the field of restorative dentistry.

Figure 1
Cerec: Prototype, Type 1, Type 2 and Type 3. Pictures by courtesy of Dentsply Sirona

Bhambhani and colleagues (2013) classify digitization in prosthodontics according to the clinical aspect, laboratory procedures, the training of students, patient motivation, practice management, and dental research. The potential benefits include, but are not limited to, enhanced motivation for patients, improved communication, use of enhanced biomaterials, reduced chair time for the patient, and providing predictable results of the treatment.

Planning
Based on the concept of informed consent, the patient and the restorative dentist should be able to make a shared decision about the treatment plan. Several 3D-digital diagnostic tools are available to achieve this kind of a communication platform, and can help to arrive at a successful, predictable, and safe treatment. Cone beam computed tomography (CBCT) data can be combined with digital
impressions of the dentition in order to create a virtual model of teeth and bone structures in three dimensions. Those 3D data sets have not only been predominantly used in orthognathic surgery and functional reconstruction of large maxillofacial defects but also in cases of complex implant replacement of missing teeth. The virtual model visualizes anatomical structures and prospected reconstruction and can help to decide, for instance, whether augmentation procedures are beneficial or whether it is possible to compensate for the implantation axis by means of the future prosthetic construction.

The wax-up made by the dental technician is a tool that simulates the final restorative treatment and has always played an important role as a communication tool for the dental technician, the dentist, and the patient, as well as serving as a diagnostic device. Once the simulation is accepted by the whole team (i.e., patient, restorative dentist, and technician), the wax-up can be transferred to the definitive restoration. Traditionally, the wax-up was manually created and used as a guideline for a try-in simulation (mock-up).

The digital workflow, however, is less time consuming, offers less asymmetry due to the digital mirror function, and, in combination with rapid prototyping, makes it possible to offer the patient different realistic designs to choose from, in one single appointment. Additionally, the digital wax-up can be easily and accurately transferred to the final restoration.

**Production**

The digitally minded practitioner can choose from a variety of rapid prototyping or CAD/CAM applications. More than a dozen different CAD/CAM polymers for semi-permanent use have been available for half a decade already, and there are now seemingly countless millable materials intended for permanent restorations. Relatively new dental CAD/CAM materials, such as polyaryletherketone, are gaining in popularity in the dental community, and modifications of traditionally hand-pressed glass-ceramics are also available and used as a CAD/CAM material without any loss in quality, while taking up significantly less working time for the dental technician. CAD/CAM polymers – sometimes referred to as “indirect composites” such as Lava Ultimate – are intended for permanent restorations and are becoming popular. Manufacturers are working on combining the mechanical properties of direct composites and indirect ceramic restorations, which makes this material class potentially very interesting for a broad range of indications.

In his well-recognized review about the digital future of dental devices, Van Noort states: “The challenge for the dental materials research community is to marry the technology with materials that are suitable for use in dentistry. This can potentially take dental materials research in a totally different direction.”

**Production – zirconia**

One of those marriages is the use of zirconia in restorative dentistry. Since the 1990s, a modification of pure zirconia has been successfully introduced to restorative dentistry due to its favorable biological, mechanical, and esthetic properties.

Zirconia (ZrO₂) is a tooth-colored oxide ceramic. It is supposedly as biologically friendly as titanium.
Osseointegration of zirconia implants, for example, is considered comparable to that of titanium implants, although human histological studies are scarce. In implant dentistry, it is not only predominantly used as a basic material for abutments but is also applied for implants. In a recent, comprehensive review by Cionca and colleagues (2017) on the current status of zirconia implants in the dental field, reasons for choosing zirconia instead of titanium implants, as derived from the literature, are listed. They include enhanced aesthetics with white zirconia and presumed sensitivity to titanium in susceptible patients – zirconia is supposedly less attractive to bacteria – along with patients’ preference for non-metallic dentistry in general.

Transformation of single crystals from the tetragonal to the monoclinical phase (t-m transformation), introduced by stress, accompanies expansion of the crystal and inhibits micro-crack propagation. This mechanism, also referred to as “transformation toughening,” makes this particular white material extraordinarily strong; it is irreversible at body temperature, which makes the process nonrecurring.

However, zirconia is a demanding associate: Due to the advanced production process, computer-aided manufacturing is mandatory, and production inaccuracies can have severe clinical consequences. Low-temperature degradation (LTD) was identified as the main reason for the catastrophic failures of hip-ball prosthesis in 2001 and 2002. It is unclear whether such catastrophic changes can also occur with dental devices under clinical circumstances.

Production – bonding to zirconia

Most applications of dental zirconia have to be bonded to a sub- or super-stratum with cement. Another major issue in the liaison between zirconia and dental material technology is the adhesion at the cement-to-zirconia interface: Microtensile tests for various bonding strategies indicate bond strengths around 16 to 23 MPa. Whereas some reviews are critically pessimistic, other authors consider this to be acceptable bond strengths. All the reviews, however, focus on the interface between zirconia and the (adhesive) cement. The influence of the mechanical and chemical properties of the sub- or super-stratum on clinical bonding failures remains unclear but is of clinical relevance.

Production – impression-taking

Alghazzawi describes the advantages of CAD/CAM technology and outlines a digital future for the field of restorative dentistry, stressing the digital impression as the most easily accessible “future” technology in the dental office.

The list of the potential advantages of digital impression-taking is extensive. Analysis of the preparation is possible in real time, and direct assessment tools are available for the dentist. The area of interest can be scanned in intervals and also selectively repeated. The dentist transfers the digital model to the technician within seconds, and disinfection is not germane. No impression or casting material is needed, while the files can easily be stored without loss of quality. This is just to mention a few of the advantages.

But there are certainly also disadvantages to digital impression-taking. The learning curve for
handling the scanning device seems to be flat and certain scan paths have to be followed. Extra equipment and maintenance is needed, and the scanner itself is quite expensive. On top of that, the digital workflow might be limited due to incompatible software or even scan fees. But what about the quality of the digital impression? Most of the studies performed showed comparable or even better results in terms of accuracy for the digital workflow for single units and short-fixed dental prosthesis (FDPs); whereas some studies show better results for analogue workflow, especially for full arch impressions.

Based on those studies, the practitioner can conclude that it is safe to use digital impression-taking for single unit restorations. Even though there are differences in the accuracy of the available scanning systems, all the systems tested generally deliver clinically acceptable results.

The expected number of treatments, the time and the aim needed to take a digital impression, along with the patients’ preference, could play a central role in decision-making about whether to invest in a digital scanning device or not.

Production – CAD/CAM

Restorative dentistry has to deal with specific features, as compared to other industrial production workflows. Whereas Rapid Prototyping (RP) normally deals with Additive Manufacturing (AM), using inexpensive material to build up a prototype for visualization and testing purposes, every dental restoration is unique, and therefore is a prototype and final product at the same time. Traditionally, AM in restorative dentistry was limited to manufacturing a “mock-up,” and Computer Numerical Control (CNC) milling was used for the final restoration. However, additive techniques, often referred to as 3D printing, are catching up. Printable biomaterials are available, and, even though current expert opinion is still critical about the use of AM in restorative dentistry, some authors report excellent or even superior accuracy in AM objects compared to CNC-milled objects in vitro.

Still, it is not just the material that matters. The CAD/CAM production process, whether or not associated with 3D acquisition to a full 3D Workflow in prosthodontics (figure 2), enables the restorative team to personalize the designated therapy by means of easily accessible restorations. Individually designed CAD/CAM implant abutments, for example, are not necessarily more expensive than their stock counterparts (e.g., zirconia abutments from Dentsply Sirona: figure 3).
Figure 2
3D Workflow, adapted from van der Meer61

3D acquisition

CA Design

Rapid prototyping

Figure 3
Stock (ZirDesign™, left) and CAD/CAM customized (Atlantis™, right) zirconia implant abutments, both from Dentsply Sirona implants, Mölndal, Sweden after one year of clinical service

The question remains, however, whether the use of individualized abutments leads to measurably significant differences in clinical everyday life.
Evaluation – visualization of the invisible

Objective measurements are needed to evaluate whether the treatment performed has met the restorative goal, or whether or not degeneration of the result takes place over time. They support – together with clinical experience – successful aftercare, on the one hand, and produce comparable outcome measurements, on the other, thus helping develop evidence-based and predictable treatment concepts. In this sense, careful evaluation and diagnosis are similar.

Traditional assessment methods are practitioner-based, and, even though more or less objective assessment methods have been developed, it is often difficult to introduce them to clinical practice. Therefore, superimposing 3D digital models could be a promising addition to visual examination and assessing restorative treatment results.

Currently, a beta version of a dental superimposing tool is already available (OraCheck by Cyfex). Even volume changes can be calculated, and the performance seems comparable to the standard superimposing software. In theory, the application seems suitable for assessing clinical wear, but an accurate superimposing strategy for the individual tooth appears to be lacking, to date.

Aim and research questions

The restorative dentist has to deal with a dilemma: He/she needs to keep up with modern technology in order to be able to offer state-of-the-art care, but the dentist also needs to identify lasting and reliable tools from the vast amount of novelties offered by the industry. The general objective of the research presented is to assess some of those novel tools and materials to help the practitioner make a choice and create awareness of this dilemma.

For a systematic division, featured in the Introduction above, clustering was chosen for different technological innovations: 1) diagnostics and treatment planning, 2) production and treatment execution, and 3) patient safety and evaluation. This thesis focuses on a selection of digital production and treatment execution related to aspects of restorative dentistry, more specifically the field of oral implantology.

The following research questions are posed:

Can zirconia implant single-tooth replacements perform in a way comparable to the gold standard (titanium implants) in terms of bone to implant contact (Chapter 2a)?

Do zirconia implant abutments exhibit bulk and/or surface degradation after one year of clinical service (Chapters 2b and 2c)?

Do zirconia implant abutments show a decrease in strength after one year of clinical service (Chapter 2c)?

Is the standard procedure for bonding Lava Ultimate crowns to zirconia implant abutments efficient (Chapter 3a)?

Does the restorative material have an influence on the debonding rate of crowns bonded to zirconia abutments (Chapters 3b and 3c)?

Is there a difference in patient appreciation and chair time between digital and conventional

impression-taking in implant dentistry (Chapter 4)?
Do customized zirconia implant abutments perform better than zirconia stock abutments after one year of clinical service (Chapter 5)?


16. Mainjot AK, Dupont NM, Oudkerk JC, Dewael TY, Sadoun MJ. From artisanal to CAD-CAM blocks: State of the art of indirect


