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CHAPTER 1

Introduction:
Overview of CAD/CAM –
basic components and procedures

Keywords: CAD/CAM, Scanning, Milling, Stereolithography, Computer Aided design (CAD), Compuer Aided Manufacturing (CAM), Computer Aided Impressioning (CAI), Drill guides, Zirconia ceramics, digital veneering.

1.1 Introduction

Computerized dentistry, especially CAD/CAM, has seen a dramatic growth during the past 20 years, and which is now accepted practice and slowly grows to maturity. However, like many other developing technologies the boundaries in the field of operation are not well defined. The development of generally accepted measurement methodology is in some cases redundant or not present at all. Evidence based data need to be collected and standards need to be developed.

The application of zirconia ceramics for the fabrication of fixed partial dentures (FPDs) has expanded rapidly in the last 10 years. The CAD/CAM technology, which is required for the processing of zirconia, has been significantly improved, leading to the achievement of high quality restorations. The number of CAD/CAM manufacturers had increased to about 100 exhibitors at the last Cologne International Dental Show (IDS) [1]. The high diversity in this field warrants an overview of the properties of the different zirconia ceramics and their dental applications.

1.2 Accuracy of Dental Scanners

The emergence of different modalities for the computerized production of custom dental devices, proper validation and verification methodology for CAD/CAM systems becomes of interest to dental professionals and custom dental device manufacturers. CAD/CAM components such as the digitization system, design software and fabrication machines are medical devices that have to perform to a certain level, whereby dental device manufacturers need to prove with reasonable assurance the safety and effectiveness of the devices [2,3].

In order to manufacture a custom prosthetic device with an automatic CAD/CAM procedure the preparation surface and surroundings need to be digitized using a mechanical [3] or optical [4,5] surface measuring device. During the entire manufacturing process, each sequential step will add to final inaccuracies, which has its limits set on 50-75 microns [6, 9, 14-16, 24, 27, 39]. In evaluating the performance of integrated, closed CAD/CAM-systems results have been obtained that fulfilled this limit. May et al [15] measured the precision of fit of the crown fabricated with CAD/CAM technology for the premolar and molar teeth fit to a die and found that the mean gap dimensions for marginal openings, internal adaptation, and precision of fit for the crown groups were below 70 microns. These findings showed that the crowns studied can be prescribed with confidence knowing that the precision of fit will consistently be less than 70 microns. To remain within this generally accepted precision the accuracy and reproducibility of the first step of surface digitization needs to be considerably lower than this value. A dental surface digitization device can be defined as: a device used to

record the topographical characteristics of teeth, dental impressions, or stone models by analog or digital methods for use in the computer assisted design and manufacturing of dental restorative prosthetic devices. Accuracy is a measure for the digitizing quality of the measured points. An existing standard for characterizing "Digitizing quality" of coordinate measuring machines has already been devised in an international standard [19], but the test methods are laborious and not dedicated to the geometries and undercut measurements that are encountered in dental surface digitization. May investigators have developed methods to evaluate the fit of restorations in-vitro [11, 17, 22, 25, 26, 30-39, 103, 126].

The first objective is to find a value for the measurement error of digitized dental surfaces by testing a new statistical evaluation method on two laser light section triangulation scanners [5].

A second objective is to evaluate whether the proposed test method using a standard artefact can serve as a dental standard for dental surface digitization devices. The test method should further provide a possibility to objectively test and compare vendor specifications [12].

The third objective was to seek suitability of the method for the development of an international ISO standard for digitizing devices used in CAD/CAM systems [23].

1.3 Approach for valuating the influence of laboratory simulation of implant placement

In the last years, dental implants faced an increasing growth of popularity. The great aesthetic rehabilitee and the tooth-saving advantages of the neighbouring teeth unlike bridges gave implants a growing demand. However, according to Massey et. al. [40] only 17.8% of the implants placed by implantologists could be classified as 'ideal' with regard to orientation. This brings a need of a technique or a method for precise surgical planning and accurate placing of implants.

New digital techniques could be used to improve localization and targeting of implant placement and reduce the inherent invasiveness of surgery. Verstreken et. al. [41] described a planning system for oral implant surgery based on a true three-dimensional approach which allows the interactive placement and adjustment of axial-symmetric models representing implants in the jawbone structures visible on computerized tomographic volume data and largely outperforms the manual planning practice based on two-dimensional dental computerized tomographic images printed or on film. Sarment et. al. [42] compared the accuracy of a conventional surgical guide to the of a stereolithographic surgical guide. The stereolithographical technique built surgical guides in an attempt to improve precision of implant placement. This improvement was proved. However, further studies were necessary

to validate its clinical use. Tardieu et. al. [43] presented a case of immediate loading of mandibular implants using a five-step procedure. The first step consisted of building a scannographic template, the second step consisted of taking a computerized tomographic (CT) scan and the third step consisted of implant planning using SurgiCase software. The final two steps consisted of implant placement using a drill guide created by stereolithography and placement of the prosthesis. Using a CT scan-based planning system, the surgeon was able to select the optimal locations for implant placement. By incorporating the prosthetic planning using a scannographic template, the treatment was optimized from a prosthetic point of view. Furthermore, the use of a stereolithographic drill guide allowed a physical transfer of the implant planning to the patient's mouth. The scannographic template was designed so that it could be transformed into a temporary fixed prosthesis for immediate loading and the definitive restoration was placed 3 months later. Di Giacomo et. al. [44] evaluated the match between the positions and axes of the planned and placed implants when a stereoplithographic surgical guide was employed. Clinical data suggested that computer-aided rapid prototyping of surgical guides might be useful in implant placement. However, the technique required improvement to provide better stability of the guide during the surgery, in cases of unilateral bone-supported and non-tooth-supported guides. Van der Zel [45] described a newly developed implant procedure CADDIMA (Computer Diagnosis and Design of Implant Abutments) to be used to virtually place dental implants and construct a precise guide splint and temporary prosthesis for delivery at the time of implant placement. The therapy is developed to improve surgical and restorative accuracy, allowing for predictable placement of implant prosthetics taking account of loading of implants through use of CT imaging, laser optical imaging, stereolithographic guides and individualized prosthetic restoration design.

Before new digital techniques and methods get success in the world of implantology further studies and information about not only the advantages and the disadvantages, but also the indications and the contra-indications are needed. However, no study about the (possible) difference in accuracy between implant placement by manual drilling without any digital planning and guidance and implant placement by drilling with computer planning and a surgical guide (CADDIMA) had been done before.

The aim of this study was to compare the orientation differences between planned and placed implants by manual drilling and by drilling with computer planning and guidance.

1.4 Computer modelling of occlusal surfaces of posterior teeth by virtual articulation

Dental restorations should offer stability in maximum intercuspidation and not interfere eccentric movements during articulation [46-52, 73-79]. The individual movement patterns of opposing tooth surfaces during function and gliding contact movements have therefore been studied comprehensively [53-56]. These movements can be simulated in different types of articulators, using settings obtained from bite registrations or by using default values for the determinants of mandibular movement [59-72]. With this information at hand and using conventional techniques for the fabrication of cast or pressed restorations, the dental technician can build-up conventional crowns with an anatomy that facilitates comfortable occlusion and articulation.

Research with respect to CAD/CAM crowns in the past has been mainly focussed on the precision of fit of the restorations and not so much on their anatomic properties. Ideal individual crown morphology is difficult to design because it requires modeling the relation between a crown and its antagonist during oral (para)function. Some sort of virtual articulator is required. With the CYRTINA CAD/CAM technique (Computer Integrated Restorative Technology by Imaging and New Acquisition) developed at the Academic Center of Dentistry in Amsterdam, The Netherlands, however it is possible to quantify the interfering portion of the occlusal form during the design process. The protocol then suggests a new occlusal form that eliminates the excursive occlusal interferences. Starting from a generic form of a molar tooth, the software modifies the design to prevent posterior occlusal interferences with the resulting mandibular movement [57]. The most important settings concern the determinants of these contact movements, mostly analyzed in anteroposterior and transverse planes. The relative influence of these determinants on the contact movements and the linked 2D occlusal design of the premolar and molar teeth has been previously investigated. In addition to these data, a validation and quantification of the determinants in the 3D perspective is essential for clinical comprehension and application. The purpose of this study is to investigate differences in the occlusal morphology of the right mandibular molar resulting from high, average and low values of settings for determinants of anteroposterior and transverse mandibular movement using computer integrated restorative technology with imaging and new acquisition.

1.5 Comparative finite element stress analysis of zirconia and titanium abutments

Zirconia was well known in ancient civilizations as a rare gem. Its name is said to be derived from the Arabic-Persian word ”Zargon” which means gold coloured stone. It was first

discovered in Germany in the seventeenth century by the chemist Martin Heinrich Klaproth. It was used in industry in areas of high chemical and mechanical stresses long before it was accepted as a biomedical material.

The introduction of 3Y-TZP zirconia as a new core material made metal free, full ceramic dental restorations possible, even in high stress areas [58, 80, 81]. Due to its mechanical and physical properties, zirconia can replace metal taking certain design parameters into consideration. Yttrium stabilized zirconia is stronger than for example titanium. The tensile strength of titanium alloys is 789-1013 MPa [82] and the tensile strength of zirconia is 1074-1166 MPa [83]. Moreover, yttrium stabilized zirconia has a high fatigue resistance caused by a martensitic transformation from tetragonal to monoclinic, which is accompanied by a volume increase of 3.5% [84]. All-ceramic restorations gained lots of attention due to their superior biocompatibility and esthetical characteristics compared to other aesthetic restorative materials which have many disadvantages as component dissolution, liquid absorption, hydrolysis, and colour change during long term service in the oral cavity [85, 98]. Although the esthetical differences between crowns on a metal or zirconia abutment are subtle, titanium has the disadvantage for dental implants of considerable bacterial accumulation on the supra-gingival part when compared to zirconia, where professional cleaning can cause damage to the relatively soft implant or supra-structure surface. Considering its (bio) material properties, zirconia has been confirmed to be a material of choice for dental prosthetic devices, and also implant-abutment systems [86, 89]. For "all zirconia implants" scientific studies are needed to fill the gaps concerning long-term clinical evaluation of these implants currently leading to propose an alternative use like a titanium implant with zirconia abutment [87].

However, the mechanical consequences of the introduction of zirconia to replace titanium have not been studied well. The influence on the stress distribution might be different for different connector systems between the implant and the abutment. Chun *et al* [88] studied the stress distribution in 1-body, internal-hex and external hex implants. However, they did not take the screw joint preload on the stresses into consideration. Considerations of abutment design and their effect on stess distribution and strength with and without fatigue loading have been reported in literature [90, 91, 96-101].

The objective of this study was to analyze with finite element analysis (FEA) the stress distribution in two implants with abutment and screw, one with an internal and one with an experimental external octagon (Dyna Dental Engineering, Bergen op Zoom, the Netherlands) with the abutment in titanium alloy or zirconia, in order to evaluate the mechanical consequences of the change of the abutment material.

1.6 Effect of design parameters on the failure strength of PRIMERO crowns

Metal-free, all-ceramic restorations have become more widely distributed due to their high esthetic potential and their excellent biocompatible properties. Today, many framework structures for prosthetic restorations are fabricated in CAD/CAM procedures, which means that a major part in the working sequence is carried out by means of industrial machines [110-115]. On the one hand, frameworks can be fabricated more efficiently. On the other hand, it is possible to achieve industrial quality standards, which are particularly important for ceramic materials. Every pore and imperfection is a potential starting point for cracks and thus for the clinical failure of ceramic restorations. The frameworks made of glass-infiltrated oxide ceramic fabricated in the slip technique exhibited large spectra of strength distribution related to the fabrication process resulting in a low-Weibull modulus. Using the same ceramic material in the form of industrial prefabricated blocks and applying the milling technique, the Weibull modulus of oxide ceramics and thus the reliability of the restorations was significantly increased. However, to-date the veneering material has been layered according to the well-known fabrication process of the metal-ceramic technique [81, 123]. According to ISO 6872 and 9693 standards a minimum flexural strength of 50 MPa for veneering glass-ceramics is required. The bond between veneering ceramic and zirconia framework is currently the subject of comprehensive investigations. The typical failure pattern of a veneering material in the daily clinical practice is known as ceramic chipping. This fracture pattern is associated with a thin layer of glass-ceramic that remains on the zirconia framework. This indicates a reliable bond of veneering ceramics to the framework, but also reveals a weakness of the veneering porcelain. A possible reason for the incidence of chippings may be found in the former limited CAD-software options by which crown and fixed dental prosthesis (FDP) frameworks could not be machined to an anatomically reduced form, offering adequate support to the veneering material. In contrast many systems could offer only uni-thickness copings for crowns as well as bar-shaped connectors for FDPs. Therefore with these systems, veneering ceramic had to be applied in thick layers to accomplish functional and esthetic demands without any cusp support. For metal-ceramic restorations, it was reported, that inadequate framework design represents one important reason for an unfavorable failure rate of the veneering material. Modern CAD/CAM-systems are able to provide a considerably better anatomically cut back framework design, thus future clinical long-term results may be more favourable [111-120, 124-139].

From an economical point of view, the esthetic and functional completion of crown and FDP frameworks involving traditional methods, such as the powder layering technique, appears to

be inefficient. One possibility for increasing the cost-effectiveness involves the industrial fabrication of veneered crowns by machining of the entire restoration by means of CAD/CAM technologies. Restorations made out of mono-blocks of either leucite-reinforced glass-ceramics with a flexural strength of around 100–150 MPa with mandatory adhesive cementation, or lithium-disilicate reinforced glass-ceramics exhibiting a flexural strength of 350–400 MPa, with the option of conventional cementation [104, 109, 122]. Therefore, the indication range is strongly limited to single crowns and small FDPs.

The combination of a CAD/CAM-fabricated framework with CAD/CAM-fabricated veneering would be of major interest. A new digital veneering procedure was developed: PRIMERO an acronym for Process for integrated Reversed Manufacturing od Esthetic Restorations for veneered all-ceramic crown restorations using a CAD/CAM-fabricated high-strength zirconia coping and a layer of porcelain veneering material [106, 140-142]. It can be assumed that the new procedure of producing a core with veneer layer by the PRIMERO CADVeneer method leads to an increase in mechanical strength compared to traditional techniques enabling a lower clinical chipping rate of the veneering material [127-168].

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