IntechOpen

IntechOpen Book Series
Biomedical Engineering, Volume 7

Computer Vision in Dentistry

Edited by Monika Elzbieta Machoy

Computer Vision in Dentistry

Edited by Monika Elzbieta Machoy

Published in London, United Kingdom







IntechOpen










Supporting open minds since 2005







Computer Vision in Dentistry
http://dx.doi.org/10.5772/intechopen.76268
Edited by Monika Elzbieta Machoy

Part of IntechOpen Book Series: Biomedical Engineering, Volume 7
Book Series Editor: Robert Koprowski

Contributors
Aswini Kumar Kar, Prabhu Yuvaraj, Shruti Vishal Dev, Loknath Garhnayak, Mirna Garhnayak, Nabagata Ganchoudhury, Purna Chandra Mishra, Sonali Perti, Tapan Kumar Patro, Csaba Dobo-Nagy, Balázs Benyó, Ji-Man Park, June-Sung Shim, Swapnil Shankargouda, Preena Sidhu, Sonica Miyyapuram, Monika Elzbieta Elzbieta Machoy

First published in London, United Kingdom, 2019 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Computer Vision in Dentistry
Edited by Monika Elzbieta Machoy
p. cm.
Print ISBN 978-1-83962-186-4
Online ISBN 978-1-83962-187-1
eBook (PDF) ISBN 978-1-83962-188-8
ISSN 2631-5343

IntechOpen Book Series
Biomedical Engineering
Volume 7

Monika Elżbieta Machoy, MD, graduated with distinction from the Faculty of Medicine and Dentistry at the Pomeranian Medical University in 2009. She is currently employed as a researcher in the Department of Orthodontics at the same university. Dr. Machoy attended a one-year scholarship program at the Ernst Moritz Arndt University in Greifswald, Germany, and a three-year internship at the Technical University in Dresden, Germany. She has been a speaker at numerous orthodontic conferences, including the American Association of Orthodontics, the European Orthodontic Symposium, and the Polish Orthodontic Society. She conducts research focusing on the effect of orthodontic treatment on dental and periodontal tissues and the causes of pain in orthodontic patients.

Editor of Volume 7:
Monika Elżbieta Machoy
Department of Orthodontics, Pomeranian Medical University
Szczecin, Poland

Book Series Editor:
Robert Koprowski
University of Silesia, Poland

Scope of the Series

Biomedical engineering is one of the fastest growing interdisciplinary branches of science and industry. The combination of electronics and computer science with biology and medicine has resulted in improved patient diagnosis, reduced rehabilitation time and better quality of life. Nowadays, all medical imaging devices, medical instruments or new laboratory techniques are the result of the cooperation of specialists in various fields. The series of biomedical engineering books covers such areas of knowledge as chemistry, physics, electronics, medicine and biology. This series is intended for doctors, engineers and scientists involved in biomedical engineering or those wanting to start working in this field.

Contents

Preface **XIII**

Section 1
Introduction **1**

Chapter 1 **3**
Introductory Chapter: Computer Vision in Dentistry
by Monika Elżbieta Machoy

Section 2
Clinical Computing in Dentistry **9**

Chapter 2 **11**
Intelligent Assisting Tools for Endodontic Treatment
by Csaba Dobo-Nagy and Balazs Benyo

Chapter 3 **31**
Optical Impression in Restorative Dentistry
by Ji-Man Park and June-Sung Shim

Chapter 4 **55**
Role of Computer Technology in Changing Smile
by Swapnil B. Shankargouda, Preena Sidhu and Sonica Miyyapuram

Chapter 5 **73**
Clinical Computing in Dentistry
by Aswini Kumar Kar, Prabhu Yuvaraj, Mirna Garhnayak, Shruti Vishal Dev, Purna Chandra Mishra, Tapan Kumar Patro, Loknath Garhnayak, Sonali Perti and Nabagata Ganchoudhury

Preface

Imaging, both two- and three-dimensional, is one of the basic foundations for success in dental work. There are many possibilities in the area of imaging and a variety of equipment that is at least partially available in every office or laboratory.

As the basis for imaging in dentistry is already digital visualization, it can be used in various devices, including computer tomographs, cameras compatible with systems for creating virtual prosthetic projects, intraoral cameras, and 3D face scanners. All these devices work independently of each other to produce digital images of the patient's mouth, but they can also be used together and thus fully exploit the potential of devices with software adapted to 3D imaging.

The currently available technical and technological imaging techniques have opened up numerous possibilities for creating visualizations useful for dentists and technicians. It is now no longer difficult to obtain a three-dimensional image of a patient's face and profile, which is used, among other reasons, to visualize changes in appearance after prosthodontic or orthodontic treatment. The same is true of obtaining detailed scans of the area to be treated; scanning provides an exact map of the working field, allowing for the planning and implementation of even very difficult dental procedures. Equally available are three-dimensional images of the patient's skull, on the basis of which it is possible to accurately estimate the possibilities of dental implantation. These images help the dentist to plan the depth of implant placement and the angle at which the implants will be inserted into the bone.

Monika Machoy, MD
Department of Orthodontics,
Pomeranian Medical University,
Szczecin, Poland

Section 1

Introduction

Chapter 1

Introductory Chapter: Computer Vision in Dentistry

Monika Elżbieta Machoy

1. Introduction

Innovative visualization techniques are becoming systematically the subject of not only academic research, but also commercial production, finding use in many areas of dentistry. This is conducive to the digitalization of dentistry and its increasing treatment and diagnostic demands. In many areas of dentistry, such as orthodontics and maxillofacial surgery, and also periodontics or prosthetics, only a correct diagnosis allows for the correct treatment plan, which is the only way to restore the patient's health. The diagnosis and the treatment plan are based on the specialist's knowledge, but are subject to a large, multifactorial risk of error. Therefore, the introduction of digital visualization is a great hope for both the physician and the patient.

This book presents a review of the latest attempts to use the applications of newest methods of visualization, taking under consideration all of the main dental specialities. Work on the introduction of computer vision has been continued for years. This book presents the latest achievements in this field, analyzing their real application and credibility.

Digitalization in dentistry has increased significantly in the last 10 to 20 years. In most developing countries, the shortage of medical and dental professionals and, most of all, perfect diagnosis increases the need for technology. This can reduce the time and the number of medical errors.

Applications in the field of dental science vary according to the needs—from dental emergencies through differential diagnosis of pain in the mouth, interpretation of radiographic images, analysis of facial growth in orthodontics, to planning the optimal prosthetics for a particular patient.

2. Application of cone-beam computed tomography in dentistry

A huge breakthrough has become universal access to very advanced visualization techniques such as tomography in an ordinary dental office. Common access to radiovisiography as well as cone-beam computed tomography (CBCT) in dental surgeries resulted in a significant increase in the quality of treatment and, most importantly, in enabling multifaceted diagnostics of a quality that earlier could only be carried out in hospitals. CBCT is a fast and safe method of imaging in dental radiology. The CBCT allows to obtain a three-dimensional image of the craniofacial region at a much lower dose of radiation in relation to conventional computed tomography (CT). CBCT is the most accurate imaging method in dentistry, maxillo-facial surgery, and laryngology.

The resulting image shows nerve canals, blood vessels, teeth, and nasal sinus. CBCT allows the imaging of all anatomical structures with accuracy impossible

IntechOpen

to obtain in another type of radiological examination. The obtained image can be repeatedly processed, measured, and visualized. Currently, advanced tomographs are produced with an increased number of imaging fields from a small S (use of endodontics and retained teeth) to the largest XL + (found in maxillofacial surgery and laryngology for imaging of the paranasal sinuses, nose, ear, and throat), also performing film visualization of the course respiratory tract, auditory canal, endoscopy of the paranasal sinuses, and assessment of the respiratory tract (treatment for snoring). The choice of the field of imaging, determined in millimeters (FOV), depends on the diagnostic needs of the physician. The patient receives the results of the tests on a CD.

The full scope of dental and laryngological diagnostics covers the field of implantology due to the assessment of the quality and quantity of bones, assessment of the location of future implants in relation to anatomical structures of nerves, maxillary sinuses, tooth roots, postoperative control, and assessment of bone graft success and implants, visualization of the planned implant placement, computerized navigation in implantology. In the field of dental and maxillofacial surgery, CBCT enables precise location of detached, supernumerary teeth, changes in the bone, assessment of pathological conditions in the upper and lower jaw, assessment of the status of paranasal sinuses, and evaluation of fractures and facial and orthognathic treatment results [1].

During endodontic treatment, the tomography helps in determining the morphological structure of roots, their number, the presence of canals, and additional channels, determining the working length and degree of root and canal curvature, evaluation of root canal fillings, periapical changes, evaluation of dental root fractures, and assessment of inflammatory root resorption [2].

In orthodontics, CBCT allows simultaneous diagnosis and cephalometric analysis, assessment of facial growth, age, respiratory function and tooth erosion disorders, and assessment of the proximity of important anatomical structures that may interfere with the course of orthodontic treatment; it is useful before embedding orthodontic mini-implants and even indispensable during attending to of the retained teeth and during functional treatment to assess the temporomandibular joint and possible disorders in its region [3].

CBCT allows to determine the location and functioning of temporomandibular joint structures and what is very important in the treatment of this joint visualization of soft tissues surrounding temporomandibular joints [4].

Periodontological patients should also be diagnosed in this way. Periodontal evaluation in the tomographic image enables detailed assessment of bone morphology (type of bone defects, etc.), assessment of seizures with tooth furcation, accurate measurement of intraosseous defects, and evaluation of dehiscence, fenestration and periodontal cysts. After the treatment is completed, it is possible to assess the effects of regenerative treatments [5].

3. Three-dimensional scans

Directly at the dentist's chair, more and more often, intraoral 3D scanner is being used allowing with exceptional accuracy to transfer the current occlusion of the patient (via digital to the computer) instead of standard and uncomfortable for the patient dental mass impressions. The study (3D scan) takes only a few minutes. Excellent quality of devices and its precision, when scanning teeth, allows you to take 20 photos per second. A few moments after the teeth have been scanned, a perfectly accurate three-dimensional model of the patient's teeth is created on the screen. Thanks to modern diagnostic technology, the 3D scanner makes a seven-mile step forward, not only in the imaging of irregularities requiring treatment, or treatment planning, but most of all simulating the effects of potential treatment. The doctor, thanks to the scanner, on the screen, prepares for the patient a digital visualization of the treatment effect in 3D, and all within 1 min. This allows the patient to see how his teeth will look after treatment before he begins. All this happens during a single visit, based on the patient's actual bite, and not, as before, only on the traditional model of impressions. What is more, the initial proposal of planned treatment can be sent to the patient by e-mail, thanks to which the patient has access to visualization of the effects of his orthodontic or prosthetic treatment at any time. Thanks to modern 3D diagnostics, the patient can safely and more comfortably go through all treatment procedures. The use of a 3D scanner is effective during teeth diagnostics and planning of the orthodontic, implantological, prosthetic, surgical, and periodontal treatment process [6].

When the patient is satisfied with the presented effects of the planned treatment, you can immediately begin the process of straightening the teeth using invisible, thermoformable caps enabling advanced and very esthetic orthodontic treatment or planned prosthetic treatment.

Orthodontic overlays are made by thermoforming in specialized laboratories, using modern technologies and digital analysis. As a result, the treatment is precise and carefully planned.

The overlays are transparent, almost invisible and therefore extremely esthetic. They are made of soft materials, without any metal elements for fixing or twisting, which makes them comfortable and does not cause pain or crease. They can be easily removed for food and cleaning, so keeping hygiene is extremely easy. They are perfectly matched to the teeth, which is why patients can laugh and talk without being embarrassed.

The computer visualization of the occlusion of the patient after using digital impression is pictured in **Figure 1**.

In this chapter, I presented shortly only a section of knowledge and possibilities related to the usage of computer visualization in dentistry. This was to give a foretaste of the chapters in the book, which are exploring this topic. I believe that the following reading will be interesting and will become a valuable source of knowledge in the described field.

Figure 1.
The computer visualization of the occlusion of the patient after using digital impression (Courtesy of Prof. Tomasz Gedrange).

Author details

Monika Elżbieta Machoy
Department of Orthodontic, Pomeranian Medical University, Poland

*Address all correspondence to: m.machoy@gmail.com

References

[1] De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature. International Journal of Oral and Maxillofacial Surgery. 2009;**38**(6):609-625. DOI: 10.1016/j.ijom.2009.02.028

[2] Patel S, Brown J, Pimental T, Kelly R, Abella F, Durack C. Cone beam computed tomography in endodontics—A review of the literature. International Endodontic Journal. January 2015;**48**(1):3-15. DOI: 10.1111/iej.13115

[3] Scarfe WC, Azevedo B, Toghyani S, Farman AG. Cone beam computed tomographic imaging in orthodontics. Australian Dental Journal. 2017;**62**(1):33-50. DOI: 10.1111/adj.12479

[4] Larheim TA, Hol C, Ottersen MK, Mork-Knutsen BB, Arvidsson LZ. The role of imaging in the diagnosis of temporomandibular joint pathology. Oral and Maxillofacial Surgery Clinics of North America. 2018;**30**:239-249. DOI: 10.1016/j.coms.2018.04.001

[5] Choi IGG, Cortes ARG, Arita ES, Georgetti MAP. Comparison of conventional imaging techniques and CBCT for periodontal evaluation: A systematic review. Imaging Science in Dentistry. 2018;**48**:79-86. DOI: 10.5624/isd.2018.48.2.79

[6] Erten O, Yılmaz BN. Turk. Three-dimensional imaging in orthodontics. Journal of Orthodontics. 2018;**31**:86-94. DOI: 10.5152/TurkJOrthod.2018.17041

Section 2

Clinical Computing in Dentistry

Chapter 2

Intelligent Assisting Tools for Endodontic Treatment

Csaba Dobo-Nagy and Balazs Benyo

Abstract

The integration of image processing in novel systems bids fair to significantly improve the endodontic practice in the near future. Also, the attempt to automatically locate and classify the root canals may result in significantly decreased chair time for both the patient and the practitioner. We focus on the shapes of human root canals and their automatic classification, methods for automatic processing, and center line identification of tooth root canal as defined previously. We introduce some micro-computed tomography image analysis methods possible for clinical implementation of cone beam computed tomography image analysis in endodontics and limitations of novel techniques. In this chapter, we present our results of segmentation and root canal identification of cone beam computed tomography images.

Keywords: image processing, skeleton extraction, cone beam computed tomography, human root canal geometry, fuzzy relations

1. Introduction

Tooth development is a more complex biological process moderated by a series epithelial and mesenchymal interactions [1]. Every developed root canal has its own individual form; therefore, visualizing and understanding root canal systems are essential for successful root canal treatment (**Figure 1**). Classifications were formulated on basis of: number and relations of canals in a single root, cross-sectional forms, and the curvature along the long axis of the main root canal [2]. Alteration of normal odontogenesis causes developmental anomalies in roots. Depending on the stage of tooth development, various anomalies either in root or root canal number or size or shape can occur [1]. The most common human root malformations include: dilacerations, taurodontism, root fusion, dens invaginatus, and C-shape canals. A new complex system has been developed for classifying root morphology, the main root canal system in relation to accessory canals and root canal anomalies [3]. A new coding system was also introduced to provide more comprehensive information on the morphological features of a specific tooth, root, and canal within a single code.

These complex data characterizing roots' inner and outer forms were provided by micro-computed tomography (μCT) technology. This technology opens a new world for fine visualization and micro-morphological characterization of dental root canals for endodontists. All of the aforementioned necessary morphological information was gained from μCT image set collected from extracted teeth scans.

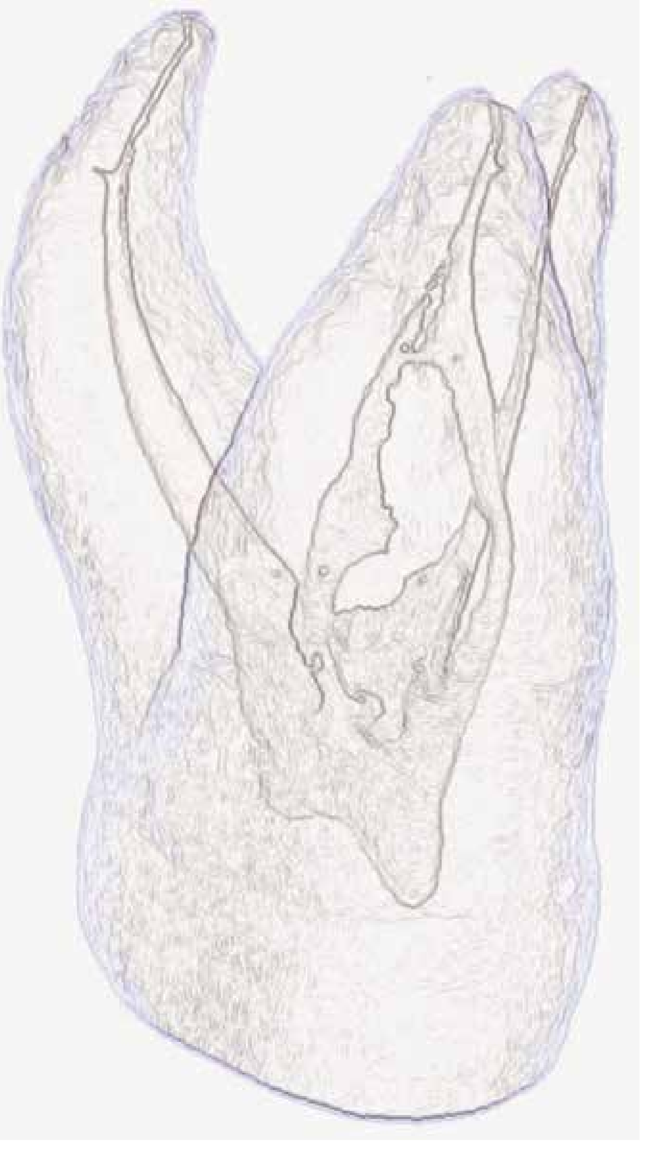

Figure 1.
Micro-CT visualization of root canal system of an upper molar from mesial view.

Clinical adaptation of this information is still limited to a few characteristics namely imaging of the outer shape of root, number and aspect of roots and root canals, main canal path, and visualization of anomalies and pathology. These limitations are due to the lower resolution provided by cone-beam computed tomography (CBCT) technology; however, information from CBCT imaging has been revolutionary, improving the clinical endodontic practice.

2. Typical shapes of human root canals and their automatic classification

On basis of serial histological sections, Hess [4] gave a detailed description about a high variety of human dental root canals. Fine detailed forms of root canals were reported demonstrating the more complexity and uniformity of a single root canal system. This excellent detailed description method is extremely time consuming and clinically irrelevant since endodontists require information on anatomy of a given root canal prior the endodontic treatment. By involving intraoral radiography, endodontists of the everyday practice collected information from periapical radiographs, mainly from clinical views. Two-dimensional radiographic image of the root canal system is hardly reliable for collecting information on the real root canal anatomy. Therefore, endodontists use not only a bucco-lingual but eccentric views, as well. Resolution and the two-dimensional nature of intraoral radiographs are the main limitations of this worldwide used technique. Intraoral radiographs provide one view information on the number of main root canals and their curvatures (mainly in the coronal and middle levels of root) but not on their cross-sectional form. On intraoral radiographs, accessory canals, fine contours of canal wall-like fins, and intricacy or isthmuses between roots are hardly detected. At this level of technology, researchers formulated classifications focusing on the curvature along the long axis of the main root canal being the most useful information gained from this technique [5, 6]. These classifications distinguish straight, gradual curve, severe curve, and bayonet forms. According to the location along the entire canal length, they defined apical or middle level (sickle shape) curvatures. Attempts had been made to use measurement for determination of canal curvatures beginning at the 1970s. All of the classifications were based on angle measurement of curvatures [7]. These authors recognized that single datum (angle measurement) is not appropriate to describe the course of canal curvature. Therefore, they used supplementary data beyond the angle measurement, for example, radius quotient [8] or radius measurement [6]. These supplementary data were meant to define localization (apical or middle level) of curvatures. The first automatic classification was introduced in 1995 [2]. Their method was based on manually defined points of imaginary root canal axis from planar radiographs; however, the classification process had been automatized. They used fourth degree polynomial approximation to the defined points of the imaginary canal axis. Then the curvature function of polynomials was calculated. Characterization of curvature functions was made the basis of automatic classification. The sign, values, and their percentage distribution along the entire length of canal were concerned (**Figure 2**). This automatic classification was able to distinguish four types of root canal forms, for example, straight (I-form), apically curved (J-form), gradually curved (C-form), and multicurved (S-form) canals.

Endodontists drew up demand on three-dimensional cleaning, shaping, and obturation of the root canal system [9]. By the last decade of the twentieth century, technology had developed to a level that it could approach the three-dimensional root canal shape in certain ways. Volume and diameters of root canals were able to be calculated by introducing computer-assisted tomography [10]. From root canal serial sections, computerized wireframe images were built up [11]. Detailed spatial reconstruction of root canal system was made by magnetic resonance microscopy [12]. Micro-computed tomography was introduced in endodontic research [13]. Before the CBCT use in dentistry, a research group provided a computer-graphics description of three-dimensional root canal axis [14]. They manually determined relevant points of root canals on Monge image pairs and calculated three-dimensional polynomial curve of root canal axis from each well-ordered Monge image pairs.

On the basis of the current state of technology, the presentation of three-dimensional axis of root canals or automatic classification of three-dimensional axes seems to provide useful information for endodontists for carrying out proper root canal treatment.

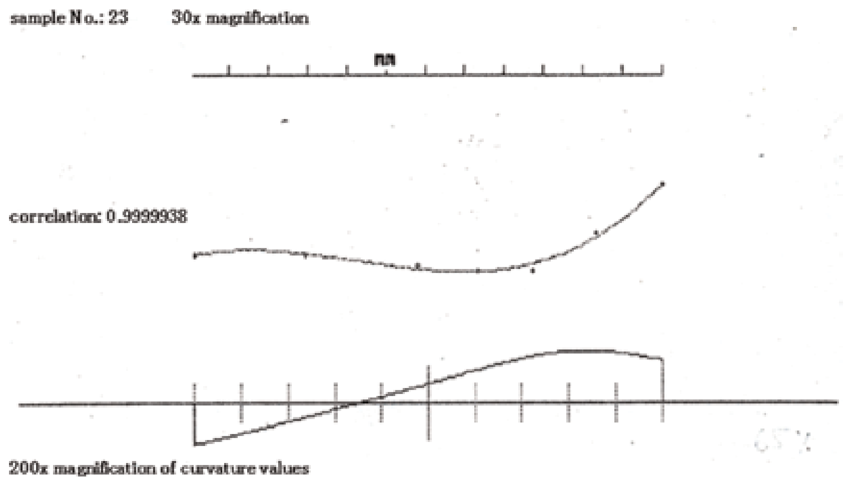

Figure 2.
Two-dimensional curvature of a single S-form root canal. Root canal axis plotted by fourth degree polynomial function approximation (above). Below the curvature function in relation of the percentage of the root length is shown. Characteristics of this form are a significant amount of both positive and negative values of curvature.

3. Image enhancement filters image classifications and segmentation methods for automatic processing

The individual root canal configuration and shape of patients, severely curved root canals, or multi-rooted teeth pose serious challenges in the automatic or semi-automatic extraction of the root canal and the identification of its center line.

3D medical imaging techniques (μCT, CBCT, etc.) enable recording 3D representation of the teeth, in which data can be processed by image processing methods to extract the shape of the root canal. Several alternative solutions have been developed for this specific problem depending on the recorded data which can be generated by different imaging modalities.

Stereo digital radiography is a relatively simple imaging modality that can be used for modeling and measurement of root canals. Analui et al. [15] developed a geometric modeling method that can be used by human dentists for the measurement of the root canal parameters. A 3D tooth model can be built using 2D radiographic images by the method suggested by Hong et al. [16]. Root canals can be detected on ultrasonic images by the fuzzy logic based method suggested by Endo et al. [17]. Lee et al. [18] developed a 3D reconstruction software and applied mathematical modeling to measure the 3D canal curvature in maxillary first molars on μCT images. 3D reconstruction algorithms are also developed for different imaging modalities: Willershausen et al. [19] proposed X-ray image-based reconstruction; van Soest et al. [20] processed optical coherence tomography images in their reconstruction method. Virtual reality-based imaging system developed by Germans et al. [21] can be used to visualize the internal surfaces of reconstructed 3D tooth structures and measure the curvature of the root canal. Root canal configuration of the teeth can be identified by the method proposed by Park et al. [22]. The identification method is specialized for the first molars and processes μC images. Quantification of the caries excavation can be solved by the method of Neves et al. [23]. Verma and Love [24] and Yamada et al. [25] proposed methods to evaluate the morphology of the root canal. Kaya et al. [26] specifically studied the root canal changes of the incisors as a result of aging. The effect of manual instrumentation on the root canal configuration is also investigated by Li et al. [27]. General features and characterization of the root canal is also possible by the modeling tool suggested by Frisardi et al. [28].

Based on this short literature survey, the image processing methods aiming the extraction of the of the root canal center line can be divided into two main phases:

1. *Root canal segmentation phase:* separation of image regions (voxels or pixels depending on the actual representation of the) belonging to the dentine and root canal (endodontium).

2. *Center line identification phase:* reconstruction of the 3D shape of the root canal and identification of the center line.

Basically, there are two general approaches that can be applied in the root canal segmentation phase:

a. Separation of the 3D data sets into a sequence of 2D images, and then processing these 2D slices individually. The information provided by the 3D data set (i.e. similarities of the identified shape and size of the root canal segments) is used only in the subsequent root canal reconstruction phase.

b. Direct processing of the 3D data sets representing the tooth.

The advantage of *approach (a)* is the problem decomposition into several smaller sized image processing steps. This problem decomposition may significantly reduce the execution time of the image processing as the image processing methods generally have relatively high computational complexity making the root canal segmentation time-consuming. The memory consumption of the image processing algorithm can also be efficiently reduced by the problem decomposition as the size of the processed individual data sets is significantly smaller than the original 3D data set. This approach is frequently applied in the case of large 3D data sets (e.g. in the case of μC images) to use the benefits of the above advantages. These 3D data sets are generally high resolution images with relatively good quality. This is an important factor in the selection of the appropriate image processing approach as the high noise/signal ratio may actually hinder the application of *approach (a)*.

The advantage of *approach (b)* is the opportunity to consider the 3D neighborhood of the processed voxel and the opportunity to involve this information into the decision about the membership status of the given voxel. This information is sometimes vital to make an appropriate decision especially in the case of low resolution images where the compensation of the so-called partial volume effect is necessary.

There are several factors that have to be considered by the implementation of both of the approaches. The signal-to-noise ratio is proportional to the X-ray dose applied during the imaging. Due to clinical considerations, the dose is kept minimal [29], and thus, the noise level in the image volumes processed is frequently high. Due to these circumstances, an efficient filtering technique has to be applied to reduce the adverse effect of high frequency noise upon segmentation, without altering or significantly reducing detectable edges. Context sensitive averaging filter proposed in [30] is an efficient tool to perform this operation.

The CT images are gray scale images where the intensity represents the attenuation coefficient measured in Hounsfield unit. The main challenge in the implementation of *approach (a)* is to find the appropriate intensity threshold value for the segmentation. Optimal clustering algorithms, such as the fuzzy c-means algorithm can be used to define the intensity threshold value in an adaptive way for each 2D slice of the data [31].

The most reasonable algorithm that can be used to implement *approach (b)* is region growing [32]. Region growing algorithms are pixel-based image segmentation methods growing homogeneous regions around the so-called seed points. The approach is very simple; the segmentation algorithm examines neighboring pixels of the initial seed points and determines whether the pixel neighbors meet the so-called homogeneity criterion. The criterion is frequently defined based on the voxel intensities of the examined region. The region is considered to be homogeneous when the standard deviation of the voxel intensities is below a given threshold. However, this approach is relatively sensitive to noise.

High frequency noises can easily result in over-segmentation, i.e., a high number of small regions. Intensity inhomogeneity of images may also cause serious challenges for the classical region growing algorithm as such a noise would avoid the creation of large homogeneous regions.

These bottlenecks of the classical region growing algorithms can be compensated by a fuzzy subset-based region growing method defined as follows. The image volume (X) is defined as a set of voxels: $X = \{x_1, x_2, \ldots, x_N\}$, where N represents the number of voxels. A *fuzzy subset* of X is defined as a set of ordered pairs:

$$F = \{(x_i, \mu_F(x_i)) | \, i = 1 \ldots N\}, \quad (1)$$

where μ_F: $X \rightarrow [0, 1]$ is called the membership function F in X. We can define a fuzzy relation in X as a fuzzy subset of X^2 written as

$$y = \{((x_i, x_j), \mu_F(x_i, x_j)) | i, j = 1 \ldots N\}, \quad (2)$$

with μ: $X^2 \rightarrow [0, 1]$. The so-called α-cut of a fuzzy subset F is the crisp set:

$$X_\alpha^{(F)} = \{x \in X | \, \mu_F(x) \geq \alpha\}. \quad (3)$$

The fuzzy relation y_α is called a fuzzy link between x_i and x_j, if:

$$\exists \alpha \in (0, 1] : \mu_y(x_i, x_j) \geq \alpha. \quad (4)$$

If a fuzzy relation y_α holds over a set $X = \{x_1, x_2, \ldots, x_N\}$, then we may write $x_i \, y_\alpha \, x_j$ $\forall x_i, x_j$ X.

Two elements x_i and x_j of a set X are α-chained, if there exists a sequence of fuzzy linked elements $\xi_1, \xi_2, \ldots, \xi_k$ in X, such as

$$x_i \, y_\alpha \, \xi_1 \, y_\alpha \, \xi_2 \, y_\alpha \, \cdots \, y_\alpha \, \xi_{k-1} \, y_\alpha \, \xi_k \, y_\alpha \, x_j. \quad (5)$$

In the fuzzy subset-based region growing algorithm, two points will be in the same segment whenever they are α-chained through neighbor voxels. In the case of tooth segmentation, the fuzzy relation allowing the separation of different tissues of tooth hast to be defined, as well as the appropriate value of α that assures the required granularity of detected segments.

The final goal is to separate the root canal from the other tissues of the tooth; thus in the segmented images, the dentine should be seen as a continuous 3D region embedding the region belonging to the root canal. Thus, the similarity between two voxels is simultaneously defined by the difference between their intensity and their distance. This compound relation can be defined similarly to the coefficients of the context-dependent filter defined in [30]. The resultant definition of the fuzzy relation contains the following product:

$$\mu_y\left(x_i,x_j\right)=\delta_y\left(x_i,x_j\right) \text{ x } \sigma_y\left(x_i,x_j\right) \tag{6}$$

The first term ($\delta_y\ (x_i,\ x_j)$) depends on the distance of the voxels. The second term ($\sigma_y\ (x_i,\ x_j)$) reflects the similarity between the intensity of the given voxels. The above terms are defined according to the following rules:

$$\delta(x_i,x_j)=\frac{1}{\sqrt{1+\kappa_\delta d(x_i,x_j)}}. \tag{7}$$

$$\sigma(x_i,x_j)=\frac{1}{\sqrt{1+\kappa_\sigma\left|\log\frac{v(x_i)}{v(x_j)}\right|}}. \tag{8}$$

where κ_δ and κ_σ are the parameters that enable tailoring the behavior of the segmentation algorithm.

4. Challenges and methods of center line identification of tooth root canal

3D curve skeletons are the collection of internal points (voxels) of an object that have the same distance from at least two boundary (surface) points of the object. Thus the center line of the root canal can be approximated by the curve skeleton of the root canal. Curve skeletons preserve the object's topology and clearly represent the hierarchy of the component objects. This is essential in the detection of root canal bifurcations. Dental root canal identification requires an appropriate curve skeleton extraction method that can yield smooth curves and is insensitive to slight changes of the object's boundary.

3D curve skeletons [33] are frequently used to approximate the topology of tubular structures such as dental root canals. A high number of curve skeleton extraction methods are published. Most of the methods are iterative algorithms that remove points (voxels) from the original volume to extract the skeleton. The thinning and boundary propagation method removes those surface points—called simple points—whose deletion will not change the topology. The topology criteria are tested by a 3D extension of the hit-or-miss transform [34, 35]. The distance field-based methods use the distance of the internal voxels (points) from the closest boundary (surface) point. The curve skeleton is approximated by the selection of the local maximums of these distance measures identifying the ridges of this distance field [36]. Geometric model-based approaches generally use a graph-based representation of the objects and create the medial lines in the form of connected curves [37]. The so-called potential field-based method applies the generalized form of the electrostatic field calculation methods known from physics [38]. The method places point charges to all the surface (boundary) voxels (points) and calculates the electrostatic field generated by these point charges. The calculated electrostatic field is used to extract a hierarchical structure composed of critical and saddle points of the field defining the curve skeleton of the object.

5. Results of segmentation and root canal identification of cone beam computed tomography images

The 3D CBCT images are frequently processed by slices as it is described in the previous sections. Typical slices of CBCT images are shown in **Figure 3**, where we can find the cross section of the same tooth on different sections of the root canal.

Due to the CBCT geometry and the low-dose imaging, the 2D images are noisy, generally affected by salt-and-pepper (impulse) noise; see (**Figure 4a**). Using simple, histogram-based thresholding for segmentation of the root canal may lead to improper root canal recognition as it can be seen in (**Figure 4b**). Thus, this noise should be filtered in the pre-processing phase of the image processing, before the segmentation of the root canal. Median filters may efficiently eliminate this kind of noise; see (**Figure 4c**). Gauss filters are also useful tools to filter out this kind of noise and make the image smoother; see (**Figure 5a, b**).

Visual representation of the segmented root canals extracted from 3D CBCT images is challenging. Point cloud visualization is a frequently used method for the

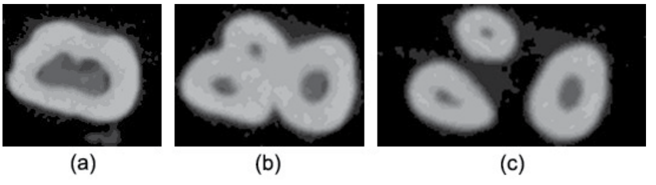

Figure 3.
Slices of CBCT images with cross section of different sections (a, b, and c) of the root canal.

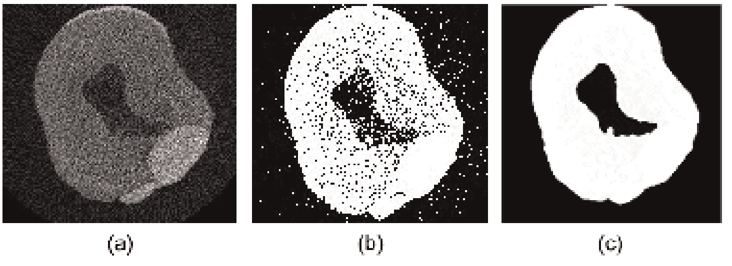

Figure 4.
A 2D slice of a CBCT image affected by salt-and-pepper (impulse) noise. (a) Original image; (b) improper root canal recognition in the original image as a result of thresholding without filtering the noise; and (c) segmentation after median filtering.

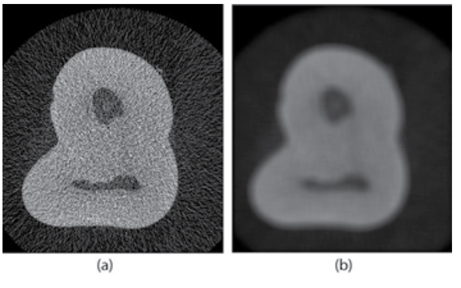

Figure 5.
Application of gauss filter on a CBCT image. (a) Original image with noise; (b) image after the application of the gauss filter.

visual interpretation of the tooth and the segmented root canal. **Figure 6a-c** are typical examples for point cloud-based visualization of the tooth.

Direct visualization of the segmented 2D images also provides the way for the representation of the segmented 3D structure of the tooth; see (**Figure 7**). The visual appearance of these 3D data sets can be improved by standard surface fitting algorithms like marching cubes method; see (**Figure 8a, b**).

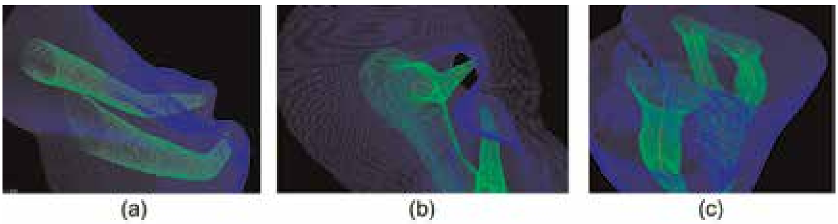

Figure 6.
Point cloud visualization of the 3D data set representing the tooth and the segmented root canal. Three different views (a), (b) and (c) of a tooth with two root canals.

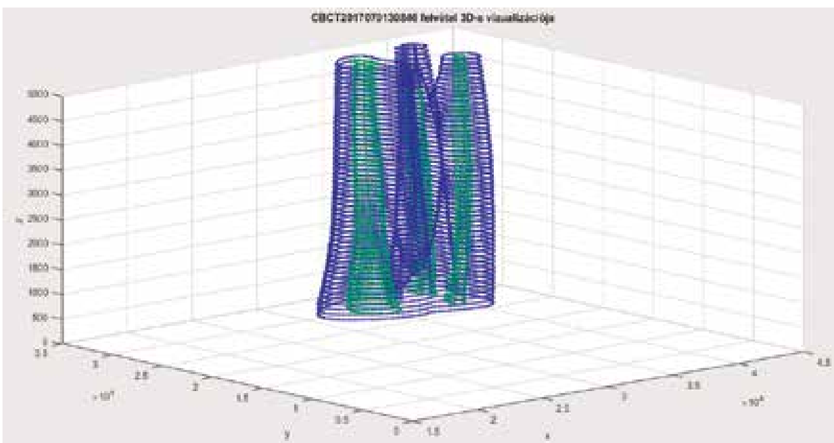

Figure 7.
Direct visualization of a 3D data set created from 2D segmented root canals.

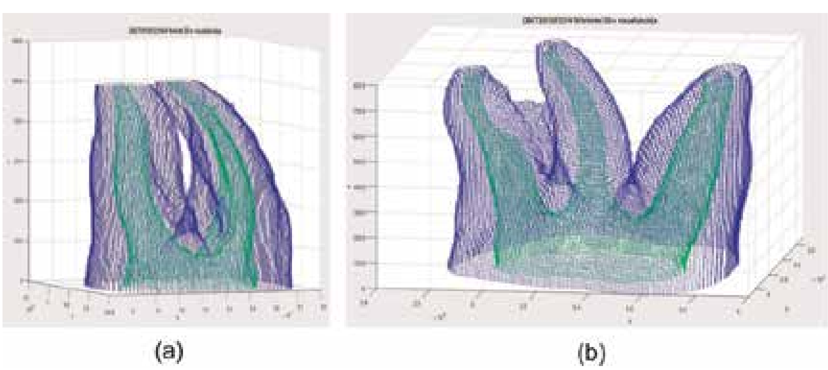

Figure 8.
3D surfaces created from segmented 2D slices by the marching cubes method. (a) A tooth with three root canals; (b) a tooth with two root canals.

6. Lessons from micro-computed tomography image analysis on extracted teeth

In a paper published in 1990 [39], μCT usability for endodontic purposes was estimated. Limited usefulness of this technique has been found in endodontics because of its high cost and of lack of adequate software available at that time. Five years later, attempts to incorporate μCT in endodontic research had been made successfully [13, 40, 41]. A consensus was made that μCT was a noninvasive technique that can accurately visualize detailed comparative data on pre- and post-instrumented canals. In an enthusiastic early study reported [13] "tremendous potential" of μCT use in endodontic research. They presented the ability of μCT assessment of area and volume change through instrumentation. Cross-sectional profile analysis was used to define canal transportation due to instrumentation. When μCT rendered image area measurement on predetermined levels of cross-section images and video-digitized physical cross-sections of root canal μCT were compared, the former was proved to be an accurate and reliable tool for experimental endodontology [41]. They also called attention to the underestimated internal area and overestimated external area measurement (approximately 3%) which was explained by the incorrect threshold determination. Bergmans and co-workers [42] used three types of software in their root canal instrumentation study. They used a volume visualization package that provided three-dimensional rendering of external and internal structure, although these renderings were not really suitable for quantitative examinations. Since the same reposition of pre and post-instrumented roots is not possible, a medical image fusion software was used for solution. This software allowed image volume alignment with subvoxel accuracy. This software analysis allowed three-dimensional root canal central axis from μCT scans. Axis was calculated by fitting a spline curve through the geometric means of wall contours on each individual slice. Application of Frenet-Serret co-ordinate frame numerical values of curvature and torsion of the curve at each point were provided. Comparison of pre and post-instrumentation spline curve canal transportation could be determined. Finally, they developed a software which implemented a true three-dimensional mathematical model for quantifying instrumentation changes. They calculated isosurfaces on pre- and post-volumes. The volume of removed dentine was calculated by subtracting pre-instrumented canal volume from post-instrumented canal volume. They visualized first untouched areas (canal wall areas which were not instrumented during enlargement) and their localizations. This unwanted result surprised endodontists who faced first with this problem and who had believed that during instrumentation, the entire or the most part of the root canal wall was cleaned. For representation of pre- and post-instrumentation fusion image, our image is shown (**Figure 9**) where a six-parameter fitting was made by Air5 package and an adaptive fuzzy C-means segmentation was used. Our representation shows a significant amount of infected debris deposition on untouched wall areas.

Recent studies [43–45] characterized the quality of instrumentation using some micro-morphological analysis developed for bone characterization which seems to be useful also in endodontic research in the following measures: surface area change (ΔSA), volume change (ΔV), and structure model index change (ΔSMI). Two-dimensional parameters at predetermined levels like area measurement, perimeter, roundness, and minor and major diameters were also defined. Center of mass change (CM shift) or canal center gravity change is a similar measurement to that of spine curve canal transportation as it is mentioned above.

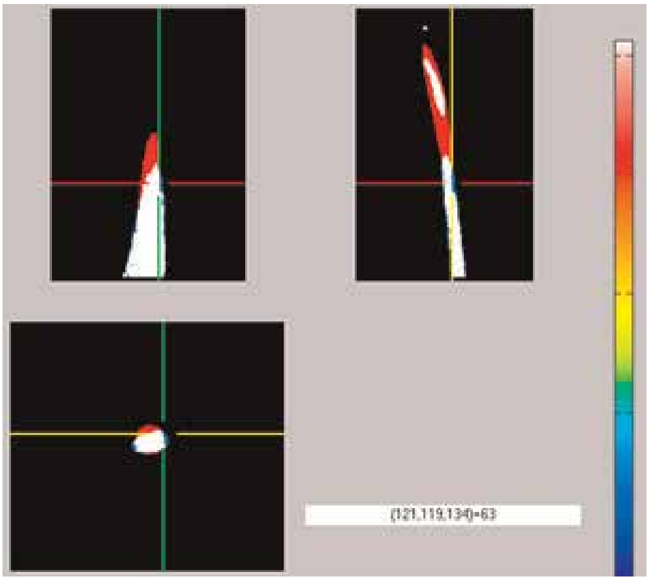

Figure 9.
A fusion image of one of our samples of pre- and post-instrumented canal in coronal sagittal and transversal views. White area represents the common part of the pre and post-instrumented canals. Red represents the enlarged part of the post-instrumented canal. Blue represents the untouched area of the original canal filled with debris.

Efficacy of residual material removal during re-treatment was assessed with μCT [46]. In a μCT study [47], it was proved that the cast post space preparation causes a higher amount of natural tooth structure loss than preparation for fiber post space.

7. Summarizing lessons gained from μCT image analysis on extracted teeth

Lesson1. Three-dimensional imaging has a great potential of studying many steps of endodontic procedures in a noninvasive manner.

Lesson 2. Recognition of the remaining high amount of untouched areas of canal wall after enlargement has turned attention of endodontists towards chemical preparation and other cleaning techniques like ultrasound or photon-induced photoacoustic streaming [24] in order to significantly improve canal preparation that will result in higher success rate of treatment expectedly.

Figure 10.
Sagittal cut of a lower incisor. The dentine shows areal transparencies especially at the apical part, which refers to more calcified dentine which absorbs x-ray photons more intensely. These areal changes of density raise difficulties for automatic segmentation.

Lesson 3. Segmentation seems to be a key point of quantitative image analysis because the dentine surface density shows areal changes along the root canal (**Figure 10**).

8. Possible clinical implementation of cone beam computed tomography image analysis in endodontics

Three-dimensional image sets from high resolution (≤100 μm) CBCT equipment have a potential to be further processed in order to assess the three-dimensional axis of the main canal or main canals. Automatic segmentation of main root canal(s) and three-dimensional root canal axis determination methods have been developed. Using these available methods, endodontists now have a possibility to introduce a canal-shape classification based on the three-dimensional root canal

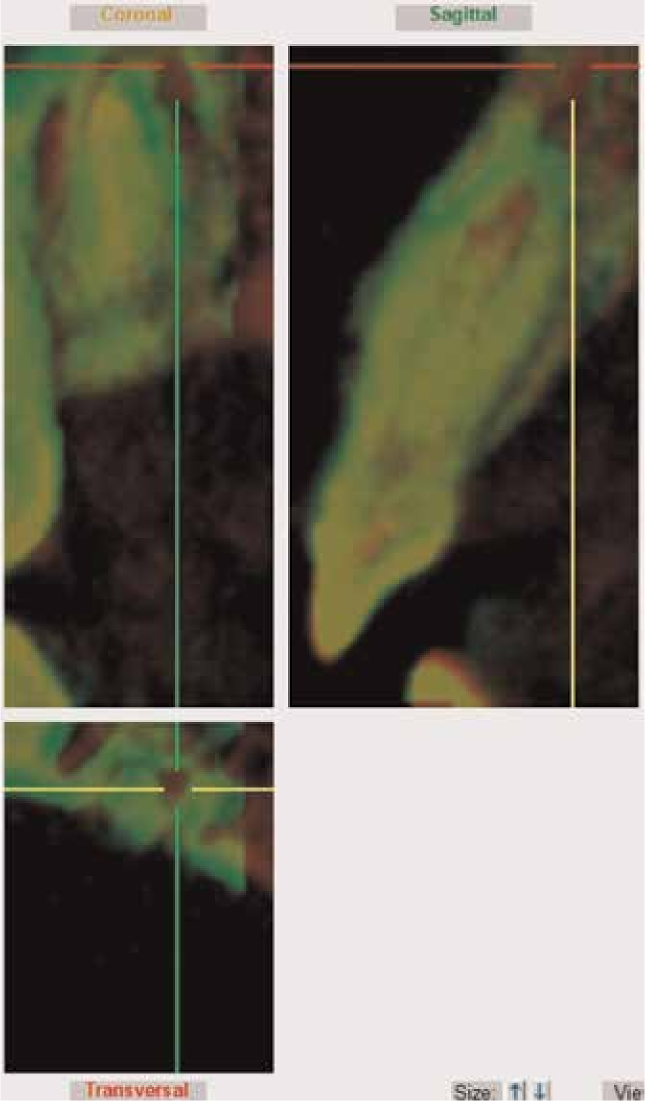

Figure 11.
Fusion image of healing of apical granuloma (courtesy of Professor Jozsef Varga). Periapical granuloma was visible at baseline (marked red) that was healed during several months of follow up (marked green) on CBCT scans. The apical granuloma located at the crosshair is visible as red on the fused images in all views.

axis. Among endodontist experts, a consensus is needed in classifications reflecting the demand of clinical challenges of root canal therapy like choosing a proper endodontic technique or choosing instrumentation what fits best to a given individual canal form. This kind of consensus-based software would significantly improve the success rate of endodontic therapy worldwide.

Image fusion method for pre- and post-instrumented canals in in vitro or ex vivo studies for quantitative and comparative analysis of different canal preparation equipment or techniques is widely used. At present level of technology, fused images have no clinical relevance in analyzing root canal instrumentation errors; however, there is a significant interest among endodontists in estimating the outcome of root canal therapy. Nowadays, endodontists have to wait a minimum of 6 months of recall for evaluating the success or failure of root canal therapy since periapical bone structural changes and their visualization require such a long period of time. Digital subtraction radiography (DSR) is a sensitive method; it can shorten the recall period for 1 month following root canal therapy. However, this method has not been widely spread in the field of dentistry, probably because some difficulties have arisen. The DSR technique was originally introduced in angiography and needs some extra image processing in dentistry like geometrical reconstruction and γ-correction of baseline and follow up radiograph pairs. An image fusion method based on three-dimensional images would be very useful, but patient's ionizing dose is still too high with CBCTs respecting the risk-benefit ratio. A CBCT image fusion case study where CBCTs were taken at endodontic treatment as baseline following a surgical treatment at some months later as follow up has already been published [49]. From the image set of this study, an apical granuloma was visible on baseline and its follow-up healing was enhanced on fuse image (**Figure 11**) presenting the possible clinical implementation of this technique.

A similar guide method used in implant surgery has been presented in some clinical endodontic cases [50, 51]. Those patients who have upper or lower incisors with obstructed and calcifically metamorphosed root canals that were not explored are potentially involved in endodontic treatment with guide. On the basis of CBCT and intra-oral scans, endodontic guides were created for the planned treatment through digital designing and rapid prototyping methods. A new artificial canal was drilled using a metal sleeve incorporated in plastic template.

Removal of adhesive fiber post avoiding root perforation, root fracture, or crack propagation is a challenge of clinicians. A three-dimensional endodontic guide method developed [52] for automatization of this procedure is increasing the success rate of less experienced dentists. Three-dimensional data from CBCT and oral cavity scanning were obtained, and computer-aided design technology generates guides with rapid prototyping to facilitate fiber post removal.

9. Limitations of novel imaging techniques and future developments

At the present level of technology, there are several limitations of CBCT equipment. CBCT is highly sensitive to movement of objects because of the small voxel size of reconstruction and of the low number of raw images used for reconstruction. In clinical situations, it is a challenge to control patient's head movements. There are some ways to improve the head movements. Supine position of the patient during scan has proven to be superior to any head support tools. Another way has been available namely an algorithm for patient movement correction. During the scan, a video capture system records the actual movements of the patient. The software analyzes and compensates for slight movements and provides improved, diagnostic quality images [53].

Another limitation of CBCTs is the development of different *artifacts* during the filtered back projection reconstruction based on Feldkamp algorithm. *Beam hardening* artifact is a real problem resulting in increased noise and misdiagnosis, for example, in root fracture. One possible solution in reducing beam hardening artifacts is application of beam hardening software. In a study where Monte Carlo analysis was used, beam hardening software reduced the beam hardening artifact errors that it was comparable with the level of error provided by synchrotron micro-CT [54].

Along with beam hardening artifact, the presence of *metal artifacts* (scatter) around the high density root canal filling material causes serious clinical diagnostic problems since the observer is unable to detect the presence of vertical root fracture [55]. Soft tissue contrast is further influenced by scatter [56]. CBCT manufacturers usually provide post-processing metal artifact reduction software and these enhancement filters have not been improved in recognition of root fracture [57]. In contrast, maximum-likelihood expectation-maximization iterative reconstruction algorithms improve the image quality and also increase signal-to-noise ratio [58]. Another way for reducing scatter significantly is introducing dual-energy imaging technology: comparison if single energy CBCT and dual-energy CBCT was dramatically reducing the metal artifact with use of upstream-filter. This method resulted also in higher signal-to-noise values [59]. First dual-energy CBCT equipment for clinical use has recently been marketed.

Photon-counting CT is a state-of-art technology with the potential to dramatically change clinical 3D imaging. Photon-counting CTs can reduce radiation dose, reconstructing images at a higher resolution, rectifies beam-hardening artifacts, optimizes the contrast agent use, and creates opportunities for quantitative imaging relative to current CT technology [60].

One of the essential limitations of current CBCT technology in detailed root canal imaging is the *voxel size*. Among the types of so-called high resolution CBCT equipment, the voxel size is between 75 and 100 micrometer [61]. At this level, the entire root canal path can be visualized. In contrast, at lower resolution equipment with 150–250 μm voxel size, the narrowest apical part of root canals cannot be visualized [62]. The diameter of physiological foramen of human molars varies between 79 and 720 μm [63]. CBCT images are not capable of giving anatomically correct images at the apex level since the apical foramen may be smaller than the adjustable voxel.

10. Conclusion

To get perspective, we remember that the best resolution in dental imaging was 2000 μm two decades earlier (this was the resolution of Scanora panoramic equipment that provided 2 mm thick layer tomograms) and today 75 μm voxel size CBCT equipment is available in the market. If you take this into consideration, this 26-times increase along with Moore's law on exponential increase chip technology is not a futuristic idea that we have 3D imaging modality with a similar resolution to that of the present μCTs in the near future. This predicts that endodontist specialists have to be prepared for understanding knowledge on lessons from μCT, must be familiar with interpreting new information, and must be able to adapt them in clinical situations in the near future.

Conflict of interest

The authors declare that they have no conflict of interest.

Author details

Csaba Dobo-Nagy[1]* and Balazs Benyo[2]

1 Department of Oral Diagnostics, Semmelweis University, Budapest, Hungary

2 Department of Control Engineering and Information Technology, Budapest University of Technology and Economics, Budapest, Hungary

*Address all correspondence to: dobo-nagy.csaba@dent.semmelweis-univ.hu

References

[1] Shrestha A, Marla V, Shrestha S, Maharjan I. Developmental anomalies affecting the morphology of teeth. Revista Sul-Brasileira de Odontologia. 2015;**12**:68-78

[2] Nagy CD, Szabo J, Szabo J. A mathematically based classification of root canal curvatures on natural human teeth. Journal of Endodontics. 1995;(11):557-560. DOI: 10.1016/S0099-2399(06)80985-4

[3] Ahmed HMA, Dummer PMH. A new system for classifying tooth, root and canal anomalies. International Endodontic Journal. 2018;**51**:389-404. DOI: 10.1111/iej12867

[4] Hess W. Anatomie der Wurzelkanale des menschlichen Gebisses mit Berücksichtigung der feineren Verzweigungen am Foramen apicale [habilitationsschift]. Ulrich Co: Zürich; 1917

[5] Zidell J. Classification of root canal system. In: Ingle JI, Taintor JF, editors. Endodontics. 3rd ed. Philadelphia: Lea & Febiger; 1985. pp. 557-560

[6] Nagy CD, Bernath M, Szabo J. A comparative study of six methods shaping the root canal in vitro. International Endodontic Journal. 1992;**25**:29. DOI: 10.1016/j.joen.2012.11.015

[7] Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surgery. 1971;**32**:271-275. DOI: 10.1016/0030-4220(71)90230-1

[8] Backman C, Oswald RJ, Pitts DL. A radiographic comparison of two root canal instrumentation techniques. Journal of Endodontics. 1992;**18**:19-24. DOI: 10.1016/S0099-2399(06)81137-4

[9] Schilder H. Cleaning and shaping the root canal. Dental Clinics of North America 1974;**23**:575-592. DOI:

[10] Mayo CV, Montgomery S, Rio C. A computerized method for evaluating root canal morphology. Journal of Endodontics. 1986;**12**:2-7. DOI: 10.1016/S0099-2399(86)80274-6

[11] Berutti E. Computerized analysis of the instrumentation of the root canal system. Journal of Endodontics. 1993;**19**:236-238. DOI: 10.1016/S0099-2399(06)81298-7

[12] Bauman MA, Doll GM. Spatial reproduction of the root canal system by magnetic resonance microscopy. Journal of Endodontics. 1997;**23**:49-51. DOI: 10.1016/S0099-2399(97)80207-5

[13] Nielsen RB, Alyassin AM, Peters DD, Carnes DL, Lancaster J. Microcomputed tomography: An advanced system for detailed endodontic research. Journal of Endodontics. 1995;**21**:561-568. DOI: 10.1016/S0099-2399(06)80986-6

[14] Dobo-Nagy C, Keszthelyi G, Szabó J, Sulyok P, Ledeczky G, Szabó J. A computerized method for mathematical description of three-dimensional root canal axis. Journal of Endodontics. 2000;(11):639-643. DOI: 10.1097/00004770-200011000-00002

[15] Analoui M, Krisnamurthy S, Brown C. Modeling and measurement of root canal using stereo digital radiography. In: Medical Imaging 2000: Image Display and Visualization. Vol. 3976. 2000, April. pp. 306-315. DOI: 10.1117/12.383053

[16] Hong SY, Dong J. 3D root canal modeling for advanced endodontic treatment. In: Smart Nondestructive Evaluation for Health Monitoring of Structural and Biological Systems. Vol. 4702. 2002, June. pp. 321-331. DOI: 10.1117/12.469891

[17] Endo M, Kobashi S, Kondo K, Hata Y. Dentistry support ultrasonic system for root canal treatment aided by fuzzy logic. In: In Systems, Man and Cybernetics, 2005 IEEE International Conference on. Vol. 2. 2005, October. pp. 1494-1499. DOI: 10.1109/ICSMC.2005.1571358

[18] Lee JK, Ha BH, Choi JH, Heo SM, Perinpanayagam H. Quantitative three-dimensional analysis of root canal curvature in maxillary first molars using micro-computed tomography. Journal of Endodontics. 2006;**32**(10):941-945. DOI: 10.1016/j.joen.2006.04.012

[19] Willershausen B, Kasaj A, Röhrig B, Marroquin BB. Radiographic investigation of frequency and location of root canal curvatures in human mandibular anterior incisors in vitro. Journal of Endodontics. 2008;**34**(2):152-156. DOI: 10.1016/j.joen.2007.09.017

[20] van Soest G, Shemesh H, Wu MK, Van der Sluis LWM, Wesselink PR. Optical coherence tomography for endodontic imaging. In: Lasers in Dentistry XIV. Vol. 6843. 2008. p. 68430F. DOI: 10.1117/12.761196

[21] Germans DM, Spoelder HJ, Renambot L, Bal HE, van Daatselaar S, van der Stelt P. Measuring in virtual reality: A case study in dentistry. IEEE Transactions on Instrumentation and Measurement. 2008;**57**(6):1177-1184. DOI: 10.1109/TIM.2008.915952

[22] Park JW, Lee JK, Ha BH, Choi JH, Perinpanayagam H. Three-dimensional analysis of maxillary first molar mesiobuccal root canal configuration and curvature using micro-computed tomography. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2009;**108**(3):437-442. DOI: 10.1016/j.tripleo.2009.01.022

[23] Neves ADA, Coutinho E, Cardoso MV, Jaecques SV, Van Meerbeek B. Micro-CT based quantitative evaluation of caries excavation. Dental Materials. 2010;**26**(6):579-588. DOI: 10.1016/j.dental.2010.01.012

[24] Verma P, Love RM. A micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth. International Endodontic Journal. 2011;**44**(3):210-217. DOI: 10.1111/j.1365-2591.2010.01800.x

[25] Yamada M, Ide Y, Matsunaga S, Kato H, Nakagawa KI. Three-dimensional analysis of mesiobuccal root canal of Japanese maxillary first molar using micro-CT. The Bulletin of Tokyo Dental College. 2011;**52**(2):77-84

[26] Kaya S, Adiguzel O, Yavuz I, Tumen EC, Akkus Z. Cone-beam dental computerized tomography for evaluating changes of aging in the dimensions central superior incisor root canals. Medicina Oral, Patología Oral y Cirugía Bucal. 2011;**16**(3):e463-e466

[27] Li KZ, Gao Y, Zhang R, Hu T, Guo B. The effect of a manual instrumentation technique on five types of premolar root canal geometry assessed by microcomputed tomography and three-dimensional reconstruction. BMC Medical Imaging. 2011;**11**(1):14. DOI: 10.1186/1471-2342-11-14

[28] Frisardi G, Chessa G, Barone S, Paoli A, Razionale A, Frisardi F. Integration of 3D anatomical data obtained by CT imaging and 3D optical scanning for computer aided implant surgery. BMC Medical Imaging. 2011;**11**(1):5. DOI: 10.1186/1471-2342-11-5

[29] European Commission. (2012). Radiation Protection no. 172. Cone beam CT for dental and maxillofacial radiology. Evidence-based guidelines. DOI: 10.2768/21874

[30] Szilágyi L, Szilágyi SM, Benyó Z. A modified fuzzy c-means algorithm for MR brain image segmentation. In: International Conference Image Analysis and Recognition. Berlin, Heidelberg: Springer; 2007. pp. 866-877. DOI: 10.1007/978-3-540-74260-9_77

[31] Szilágyi L, Szilágyi SM, Benyó B. Efficient inhomogeneity compensation using fuzzy c-means clustering models. Computer Methods and Programs in Biomedicine. 2012;**108**(1):80-89. DOI: 10.1016/j.cmpb.2012.01.005

[32] Benyó B. Identification of dental root canals and their medial line from micro-CT and cone-beam CT records. Biomedical Engineering Online. 2012; **11**(1):81. DOI: 10.1186/1475-925X-11-81

[33] Cornea ND, Silver D, Min P. Curve-skeleton properties, applications, and algorithms. IEEE Transactions on Visualization and Computer Graphics. 2007;**13**(3):530-548. DOI: 10.1109/TVCG.2007.1002

[34] Ma CM, Sonka M. A fully parallel 3D thinning algorithm and its applications. Computer Vision and Image Understanding. 1996; **64**(3):420-433. DOI: 10.1006/cviu.1996.0069

[35] Palágyi K, Kuba A. A parallel 3D 12-subiteration thinning algorithm. Graphical Models and Image Processing. 1999;**61**(4):199-221. DOI: 10.1006/gmip.1999.0498

[36] Pudney C. Distance-ordered homotopic thinning: A skeletonization algorithm for 3D digital images. Computer Vision and Image Understanding. 1998;**72**(3):404-413. DOI: 10.1006/cviu.1998.0680

[37] Wu FC, Ma WC, Liang RH, Chen BY, Ouhyoung M. Domain connected graph: The skeleton of a closed 3D shape for animation. The Visual Computer. 2006;**22**(2):117-135. DOI: 10.1007/s00371-005-0357-4

[38] Cornea ND, Silver D, Yuan X, Balasubramanian R. Computing hierarchical curve-skeletons of 3D objects. The Visual Computer. 2005; **21**(11):945-955. DOI: 10.1007/s00371-005-0308-0

[39] Tachibana H, Matsumoto K. Applicability of X-ray computerized tomography in endodontics. Endodontics & Dental Traumatology. 1990;**6**:16-20. DOI: 10.1111/j.1600-9657.1990.tb00381.x

[40] Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. Journal of Endodontics. 1996;**22**:369-375. DOI: 10.1016/S0099-2399(96)80221-4

[41] Rhodes SJ, Ford Pitt RT, Lynch AJ, Liepins JP, Curtis VR. Micro-computed tomography: A new tool for experimental endodontology. International Endodontic Journal. 1999; **32**:165-170. DOI: 10.1046/j.1365-2591.1999.00204.x

[42] Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P. A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography. International Endodontic Journal. 2001; **34**:390-398. DOI: 10.1046/j.1365-2591.2001.00413.x

[43] Zuolo ML, Zaia AA, Belladonna FG, Silva EJNL, Souza EM, Versiani MA, et al. Micro-CT assessment of the shaping ability of four root canal instrumentation system in oval-shaped canals. International Endodontic Journal. 2018;**51**:564-571. DOI: 10.1111/iej.12810

[44] Versiani AM, Carvalho KTK, Mazzi-Chaves FJ, Manoal D, Sousa-Neto DM. Micro-computed tomographic evaluation of the shaping ability of XP-endo shaper, iRaCe, and edgefile system in long oval-shaped canals. Journal of

Endodontics. 2018;**44**:489-495. DOI: 10.1016/j.joen.2017.09.008

[45] Marceliano-Alves MFV, Sousa-Neto MD, Fidel SR, Steier L, Robinson JP, Pécora JD, et al. Shaping ability of single-file reciprocating and heat-treated multifile rotary systems: A micro-CT study. International Endodontic Journal. 2015;**48**:1129-1136. DOI: 10.1111/iej.12412

[46] Roggendorf JM, Legner M, Eberrt J, Fillery E, Frankerberger R, Friedman S. Micro-CT evaluation of residual material in canals filled with Activ GP or GuttaFlow following removal with NiTi instruments. International Endodontic Journal. 2010;**43**:200-209. DOI: 10.1111/j.1365-2591.2009.01659.x

[47] Ikram HO, Patel S, Sauro S, Mannocci F. Micro-computed tomography of tooth tissue volume changes following endodontic procedures and post space preparation. International Endodontic Journal. 2009; **42**:1071-1076. DOI: 10.1111/j.1365-2591.2009.01632.x

[48] Peters OA, Bardsley S, Fong J, Pandher G, Divito E. Disinfection of root canals with photon-initiated photoacoustic streaming. Journal of Endodontics. 2011;**37**:1008-1012. DOI: 10.1016/j.joen.2011.03.016

[49] Mensch K, Simonffy L, Cs D, Szabó BT, Varga J, Juhász A, et al. Endodontic and microsurgical treatments of maxillary lateral incisor dens invaginatus in combination with cone-beam-computed tomography fusion imaging. Oral Radiology. 2017;**33**:147. DOI: 10.1007/s11282-016-0257-5

[50] van der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D computer aided treatment planning in endodontics. Journal of Dentistry. 2016;**45**:67-72. DOI: 10.1016/j.jdent.2015.11.007

[51] Connert T, Zehnder SM, Weiger R, Kühl S, Krastl G. Microguided endodontics: Accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. Journal of Endodontics. 2017;**5**:1-4. DOI: 10.1016/j.joen.2016.12.016

[52] Maia LM, Júnior Moreira G, Albuquerque RC, Machado VC, Silva NRFA, Hauss DD, et al. Tree-dimensional endodontic guide for adhesive fiber post removal: A dental technique. The Journal of Prosthetic Dentistry. in press 2018. DOI: 10.1016/j.prosdent.2018.07.011

[53] Spin-Neto R, Matzen LH, Schropp L, Gotfredsen E, Wenzel A. Factors affecting patient movement and re-exposure incone beam computed tomography examination. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology. 2015;**119**:572-578. DOI: 10.1016/j.oooo.2015.01.011

[54] Kovács M, Danyi R, Erdélyi M, Fejérdy P, Dobo-Nagy C. Distortional effect of beam-hardening artefacts on microCT: A simulation study based on an in vitro caries model. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics. 2009;**108**: 591-599. DOI: 10.1016/j.tripleo.2009.06.009

[55] Kovács M, Fejérdy P, Nagy Cs D. A fém műtermék a fejnyaki cone-beam CT (CBCT) képeken. Fogorvosi Szemle. 2008;**5**:171-178

[56] Tofts PS, Gore JC. Some sources of artefact in computed tomography. Physics in Medicine and Biology. 1980; **25**:117-127

[57] Ferreira JB, Christovam IO, Alencar DS, da Motta AFJ, Mattos CT, Cury-Saramago A. Accuracy and reproducibility of dental measurements on tomogrphic digital models: A systematic review and meta-analysis. Dento Maxillo Facial Radiology. 2017; **46**:20160455. DOI: 10.1259/dmfr.20160455

[58] Bechara BB, Moore WS, McMahan CA, Noujeim M. Metal artefact reduction with cone beam CT: An in vitro study. Dento Maxillo Facial Radiology. 2012;**41**:248-253. DOI: 10.1259/dmfr/80899839

[59] Iramina H, Hamaguchi T, Nakamura M, Mizowaki T, Kanno I. Metal artifact reduction by filter-based dual-energy cone-beam computed tomography on a bench-top micro-CBCT system: Concept and demonstration. Journal of Radiation Research. 2018;**59**:511-520. DOI: 10.1093/jrr/rry034

[60] Willemink JM, Pourmorteza A, Pelc JN, Fleischmann D. Photon-counting CT: Technical principles and clinical prospects. Radiology. 2018;**289**:293-312. DOI: 10.1148/radiol.2018172656

[61] Kiljunen T, Kaasalainen T, Suomalainen A, Kortesniemi M. Dental cone beam CT: A review. Physica Medica. 2015;**31**:844-860. DOI: 10.1016/j.ejmp.2015.09.004

[62] Szabó BT, Pataky L, Mikusi R, Fejérdy P, Dobo-Nagy C. Comparative evaluation of cone-beam CT equipment with micro-CT in the visualization of root canal system. Annali Dell'Istituto Superiore Di Sanitá. 2012;**48**:49-52. DOI: 10.4415/ANN_12_01_08

[63] Abarca J, Zaror C, Monardes H. Morphology of the physiological apical foramen in maxillary and mandibular first molars. International Journal of Morphology. 2014;**32**:671-677. DOI: 10.4067/S0717-95022014000200048

Chapter 3

Optical Impression in Restorative Dentistry

Ji-Man Park and June-Sung Shim

Abstract

Intraoral scanners are responsible for data acquisition in digital workflow, which represents the first step in restorative dentistry. The present chapter aimed to investigate the various methods for acquiring oral information, diverse clinical applications based on optical impression technique, use of intraoral scan data according to the need for model, and the various considerations regarding the selection of intraoral scanners suitable for clinical goals. The acquired optical impression data can be sent anywhere in the world, which offers the advantage of overcoming any temporal or spatial constraints. The purpose of this chapter is to understand digital workflow using optical impression and to learn how to use it effectively in clinical practice.

Keywords: optical impression, intraoral scanner, digital workflow, CAD-CAM, digital dentistry

1. Introduction

Since its first application in restorative dentistry by Francois Duret in 1973, computer-aided design/computer-aided manufacture (CAD/CAM) has become engrained in dental practice. The workflow of the manufacturing of prostheses via digital restorative dentistry can be divided into three steps: image acquisition, in which the structure inside the oral cavity is documented; CAD, the acquired images are imported to a computer program to design the desired restoration; and CAM, the restoration is manufactured from the desired material based on the design data. In the image acquisition stage, an intraoral scanner may be used to scan the oral cavity, or a stone model can be scanned after impression making and stone pouring procedure. In the CAD step, different software (S/W) modules can be used to design various types of prostheses, such as a crown, removable partial denture, complete denture, and implant surgical guide. The methods used in the CAM step include computerized numerical control (CNC) milling and 3D printing, which is also called as rapid prototyping or additive manufacturing. The milling process can be further split into the tool-path-calculation and milling processes; the former converts the path that the milling drill must pass through into numeric values to inform the latter process, the three-dimensional subtractive production of the designed prosthesis. 3D printing can be divided into the support positioning and slicing processes; the former entails the formation of supports to hold the designed prosthesis from below, while the latter refers to the actual printing of the designed prosthesis.

Dental CAD/CAM systems are categorized according to how data is acquired and whether the restoration can be fabricated within the dental office on the same day.

Hence, such the systems can be divided into in-office or in-lab systems, the former of which is further distinguished according to whether the dental office is equipped with a milling machine. The material used in an in-office system is relatively expensive because it uses a Mandrill type, which is used in small milling machines and manufactured exclusively for dental application; moreover, the material is also limited to manufacturing inlays and single crowns. However, it offers the advantage of being an all-in-one system that allows the finished product to be obtained within the dental office. An in-lab system involves transferring the data scanned from the patient to a laboratory equipped with the capacity to manufacture a range of prostheses. With traditional LAVA and Procera systems, the laboratory can produce zirconia crowns by scanning a plaster model with a desktop scanner; or the plaster modeling process can be precluded by directly acquiring a digital impression with an intraoral scanner, which further shortens the time required for the model preparation and allows the manufacture of the prosthetic to be completed at any laboratory in the world.

The intraoral scanner was originally invented by Mörmann and Brandestini, and was first applied to patient care in 1985. The technology was confronted by the difficulty of accurately scanning a wide area: the intraoral scanner was limited by the size of the optical window of its scanner tip; spatial data of the oral cavity consequently needed to be aggregated to complete an image of the entire area. Recent advances in optical systems and image processing S/W have led to the gradual expansion of their applicability. Indications that were limited to just inlays or single crowns are now being used in larger cases, including longer fixed dental prostheses and implant prostheses, as well as various intraoral devices, such as implant surgical guides, individual trays for dentures, and metal frameworks of removable partial dentures. Accordingly, this chapter will examine the current state of using intraoral scanners in restorative dentistry for optical impressions and considerations when assessing the performance of intraoral scanners.

2. Classification of methods for acquiring oral information

2.1 The inception of intraoral scanning, in-office systems

The in-office system has a lengthy history that spans over 30 years since the introduction of CEREC in 1987. It now allows for the same-day manufacture and installation of dental restorations using a small dental milling machine. This system is also referred to as an all-in-one system since it is equipped with an intraoral scanner for image acquisition, CAD and tool-path calculation S/W for restoration design, and milling machine. Dentsply Sirona is the supplier of CEREC-branded products, and together with monochrome photography-based Bluecam, color video-based Omnicam, and the low-cost APOLLO Di, it offers various systems according to the different grades of intraoral scanners. In addition, the E4D dentist system that partially includes CEREC technology has continued to evolve, and now Planmeca supplies this intraoral scanner system called PlanScan. Carestream has introduced photography-based CS3500 and video-based CS3600 intraoral scanner systems. On account of being all-in-one systems, many are closed architecture systems with a limited ability to export scanned data for use in other S/W; however, there is a growing trend favoring open architecture systems.

2.2 Popularization of digital-age, in-lab systems

CAD/CAM systems already feature a broad range of applications in dentistry, even without the added benefits of an intraoral scanner. The CNC milling process that allows for enlarged manufacture at the same magnification to overcome the properties of zirconia by showing change in volume during sintering is an outcome that has long since been integrated into dental practice. Desktop scanners used in laboratories to scan plaster models use a traditional method based on the principle of active triangulation; as a result, the image acquisition unit is fixed on the upper part of the scanner. It is consequentially difficult for the scanner to register areas where undercuts may occur, such as the sub-marginal area and proximal surface of the abutment teeth, which require die work to separate the abutment teeth after producing the plaster model (**Figure 1**). To ease the time constraints associated with pouring the plaster and separating the dies, attempts have been made to directly scan the impression without pouring plaster over the impression or acquiring data directly from the impression taken with a plastic tray by using a cone beam CT scanner, which is installed in most dental offices today. Difficulties with scanning thin, long teeth with impression scanning technique and low data-resolution images acquired by CT scanning still remain to be addressed. The latest trend in desktop scanners have evinced progress towards making scanning more convenient and efficient, and there is a change towards creating open designs that lack a door by using light sources with shorter wavelengths.

2.3 Advances in intraoral scanners, open architecture intraoral scan systems

Ever since intraoral scanners became readily available in dentistry, they have played a role in the first step of workflow for the fabrication of prostheses. The acquired data can be sent instantaneously anywhere in the world, which offers the advantage of overcoming any temporal or spatial constraints. Because an intraoral scanner must acquire data from a limited space by imaging small structures in the oral cavity with many undercuts, it is based on a principle different than that which informs desktop scanners, which fix the image acquisition unit to the upper

Figure 1.
Model scanning process through the desktop scanner. Because of the undercut area, an abutment scan is required separately. It is necessary to perform the die trimming process of the stone model.

part of the scanner and use proprietary technology patented by the company that manufactured the scanner. The CEREC system featured a “closed system” in which all workflow takes place within the in-house system. After the introduction of iTero scanners (Align Technology Inc.) in 2006, which are based on an “open system” that acquires scanned data usable in various S/W, intraoral scanner became increasingly popular among clinical dentistry practices.

The operating principles behind intraoral scanners include the active triangulation used mostly in the CEREC system and confocal microscopy chosen by iTero and Trios (3Shape) systems. The operating methods of intraoral scanners can be divided into image-stitching and video-sequencing methods. Intraoral scanners underwent rapid advances in hardware since the mid-2000s, which included various advances in anti-fog heating devices, color scanning, portable design, and video imaging methods. Advances in S/W have followed suit, including improvements in the stitching of scanned data and upgrades in intuitive scan S/W interfaces. Recently introduced intraoral scanners reflect endless improvements in their convenience and efficiency in actual clinical practice by making them smaller, wireless, light-weight, and cost-effective, as well as supporting database through cloud computing. Further, the availability of intraoral scanners has risen sharply owing to the reduction in patient discomfort and increased clinical efficiency of dentists.

3. Various clinical applications through obtaining optical impression

We have examined various scanning systems in restorative dentistry that apply CAD/CAM technology. Here, we will examine how digital technology is actually being used and applied based on actual clinical cases.

3.1 Use in diagnostic fields

When the 3D positional relationships between teeth need to be determined for diagnosis and treatment planning in cases with poor occlusal relationship between upper and lower teeth, it is common to perform alginate impression taking, followed by the analysis of the diagnostic model mounted on the articulator. In particular, much information can be gained from the contact relation during lateral movement and relationship of the upper and lower molars from the distal-to-mesial direction that cannot be seen inside the oral cavity, a considerable amount of preparation time is required to build the plaster model and mount it, which makes it impossible to see the outcome on the same day the patient was admitted. However, using an intraoral scanner to obtain a digital impression of the region of interest allows the data to be used immediately for diagnosis without the delay required for plaster setting time. An oral examination was performed on a patient who was admitted to the department of prosthodontics after placement of three implants in the left upper molar region. The patient showed poor occlusion due to a buccally collapsed upper second molar, which is the antagonist tooth. In this case, it was difficult to decide whether to fabricate the implant restoration as is or to do so after restoring the occlusal relationship first by performing a root canal treatment on the collapsed opponent tooth and covering it with a single crown. By taking an optical impression on the day of diagnosis and importing it into CAD software, the superstructure was designed on top of the implant and the occlusal relationship with the opponent tooth could be assessed from the distal direction. This was helpful in determining the treatment plan during patient consultation on the day of the visit and the patient was highly satisfied after implant prosthesis was installed (**Figure 2**).

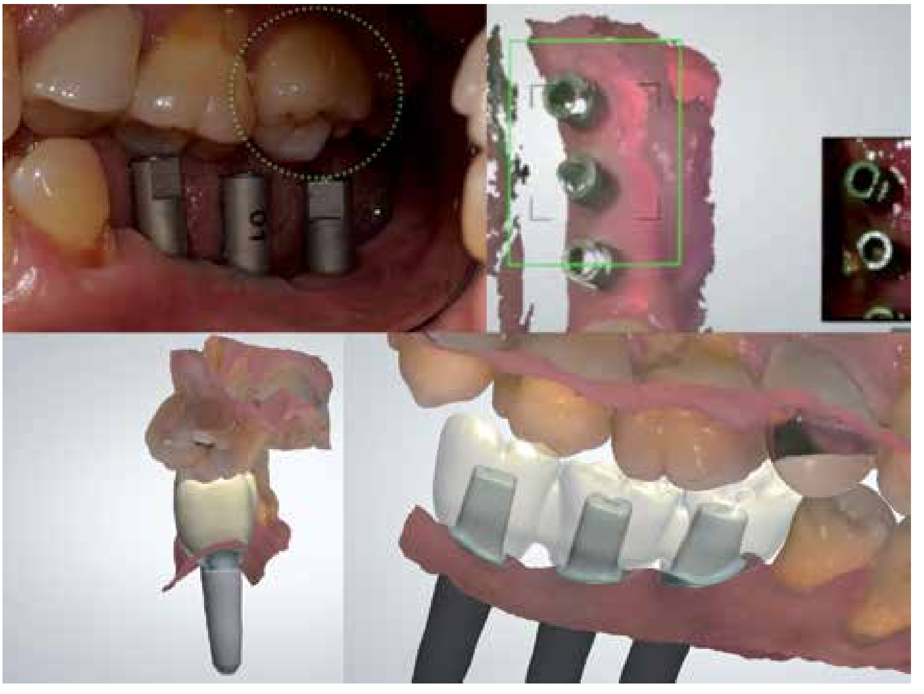

Figure 2.
Cases of using an intraoral scanner as a diagnostic tool. After taking a digital impression, the treatment plan was established by diagnosing the occlusal relationship in the distal direction, which obscures the interior of the patient's oral cavity.

3.2 Use in fixed dental prosthesis

For esthetic restoration performed by acquiring data on anterior teeth via intraoral scanning, crowns may be fabricated via a direct wax-up of the cast to reproduce the 3D characteristics of teeth surface. The crown fabrication and installation involves 3D printing of a model based on data from intraoral scanning, wax-up on the die, investment and burn-out, and pressing of the esthetic material.

A male patient in his 20s was admitted for restoration of two upper central incisors at a stage when he was about to complete his orthodontic treatment. Because the orthodontic bracket remained on the labial surface of his anterior teeth, the impression body could not be removed once the impression material hardened with the traditional impression method using silicon impression material; blocking out the bottom portion of the bracket with utility wax would not allow the shape in that area to appear on the impression body. Accordingly, instead of using such method, digital impression was taken using intraoral scanner (Trios, 3shape). After designing the rapid prototype in a model builder program, the model was obtained by 3D printing. After assuring the esthetic surface texture of the anterior teeth via wax-up on the printed die, it was fabricated by investment and pressing with lithium disilicate (eMax, Ivoclar) (**Figure 3**).

A female patient in her 30s visited the clinic for fabrication of a 5-unit fixed dental prosthesis. The patient was pleased with the shape of the provisional teeth and its shape was replicated for permanent restoration. The optical impression was obtained for abutment and provisional restoration and the restoration was designed by the "double scan" technique. While referencing the relationship between the opponent and adjacent teeth on the 3D printed model, porcelain was built on top of the zirconia coping to complete the final restoration (**Figure 4**).

Figure 3.
A digital impression was taken to fabricate the prosthesis without removing the orthodontic bracket. After model fabrication by 3D printing, the detailed features of the anterior teeth surface were reproduced via a wax-up process, and the prosthesis fabricated by pressing using lithium disilicate was installed.

3.3 Removable partial denture metal framework, more intuitive design

Because an intraoral scanner is a device that reproduces a 3D structure based on images, functional impression that selectively presses the tissues or border molding that physically takes an impression of the maximum vestibular depth without impeding the movement of the cheeks and tongue by moving the neighboring muscles is impossible. Moreover, because an edentulous arch does not have 3D features, continuously stitching small images determined by the size of the scanner tip can introduce multiple errors and the tissue surface being shiny makes it even more difficult. Therefore, instead of using an intraoral scanner, a desktop scanner obtaining image of master cast made from a traditional functional impression is recommended for cases of removable dentures.

Concerning a 74-year-old male patient who wanted a mandibular partial denture, zirconia surveyed restoration fabricated by milling based on a design that considered the path of insertion and removal of the denture in CAD S/W after digital intraoral scanning (iTero, Aligntech) was installed into the oral cavity of the patient. Subsequently, a master cast was obtained by functional impression taking, which was scanned and the design S/W, exclusive for partial dentures (Freeform, SensAble), was used for electronic surveying to determine the optimal path of insertion and removal by adjusting the inclination of the cast in consideration of the amount of undercut in the entire arch in a virtual space. To design the metal structure, the area that would be covered with the denture base was determined and the finish line was set after forming a lingual bar major connector. A rest was designed and a butt-joint was added. After designing the lattice-structure of the minor connector that joins the denture base to the major connector, a retentive arm determined via electronic surveying was added to the undercut area of the retentive

Figure 4.
The outer appearance of the provisional restoration that the patient had become accustomed to from prolonged use after extraction was replicated via a double scan technique after optical impression.

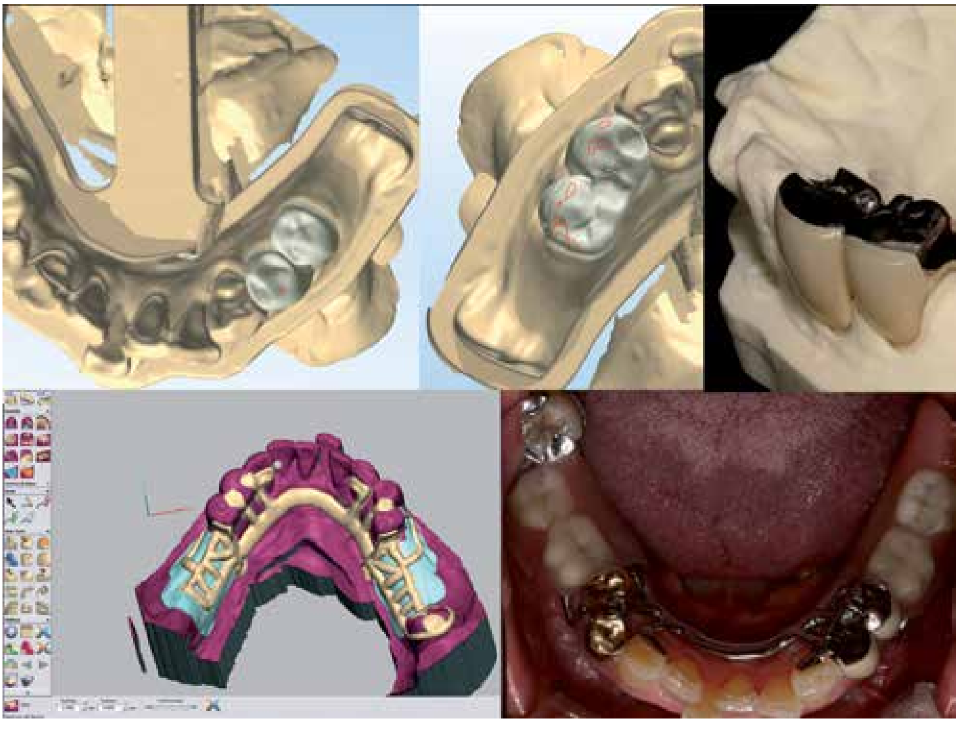

Figure 5.
A surveyed restoration was fabricated according to the path of insertion and removal of denture shown on data obtained from intraoral scanning. After using burn-out resin to print the framework structure designed by electronic surveying, the partial denture was fabricated by investment casting.

tip to complete the framework design. After reviewing the overall design, sprues for the metal casting were also designed. Plastic material that could be burned out was used for 3D printing to invest and cast the metal structure, after which the denture was completed by a traditional denture curing process for installation (**Figure 5**). The function of the retentive arm operated clearly during denture installation and removal due to electronic surveying. This system uses a unique input tool called a haptic interface. Once the mouse arrow touched the polygon wall, the arrow could not move any farther inward through a forced feedback effect, whereby the 3D shape of the teeth model could be formed with tactile feedback.

3.4 Use in complete denture cases

For the digital complete denture, a model scanning is mainly performed. Several companies have introduced systems that shorten patient visits by integrating treatment steps. Denture base resin materials must prevent discoloration and contamination while functioning inside the oral cavity for an extended period. Therefore, the materials must have particles that are smooth and densely packed. Heat-curing resin has therefore been used as the material for a complete and partial denture base. To withstand the packing pressure of resin, a frame with plaster material and metal flask are made. Subsequently, the complete curing of resin is induced by boiling it in a water tank. In the digital process, the denture profile can be milled or 3D printed after CAD design. Companies that manufacture and supply digital complete dentures use their own proprietary methods to overcome these limitations, including the use of hard resin with densely packed particles, milling a resin disk block

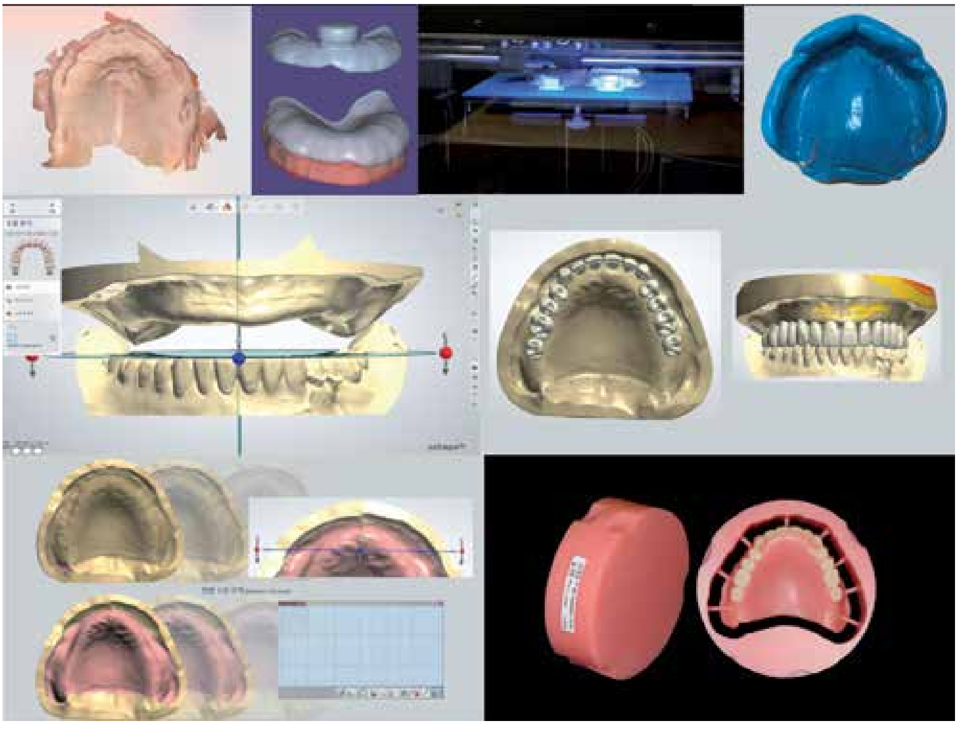

Figure 6.
The individual tray was designed and 3D printed on the edentulous data obtained by the intraoral scanner, and the functional impression was made. The complete denture module was used to design the shape of the tooth array and the denture base. The denture base was machined with a milling machine, and then the artificial teeth which are the same as the library were bonded on it.

that is larger than the complete denture being fabricated. Another attempt involves 3D printing the flask itself, which functions as a negative mold of the denture base through the traditional packing and curing process. After designing the denture, a try-in denture may be provided to check whether the denture fits the lips and facial shape of the patient. Moreover, to improve communication between the dentist and lab technician with regard to denture design, webpages are available with interfaces allowing the dentist to check and freely modify the design once the alignment of the prosthetic has been completed (**Figure 6**).

3.5 Various applications in implant cases

When fabricating a computer-guided implant surgical template, guides with replication of radiographic template tissue surface obtained from CT data have poor internal adaptation due to limitations in the resolution on CBCT, which can lead to poor stability during the surgery and diminish the accuracy of implant placement. These deficiencies can be improved by matching the cast scan or intraoral scan data with CT results. A 52-year-old male patient visited the clinic, wanting three implants in his lower right molar region. The implant placement was planned by matching the data obtained from iTero intraoral scanner and CBCT. A surgical guide was fabricated using a 3D printed wax model. Because the fabrication used high-resolution data, the guide functioned stably during the procedure, despite the fact that it was a dentulous case that did not use a separate fixing pin. After implant healing, the digital intraoral impression was made and the customized abutment and superstructure were fabricated (**Figure 7**).

Figure 7.
The CBCT and intraoral digital impression data were matched to establish an implant plan that avoided the inferior alveolar nerve. A computer-guided implant surgical template was made on the 3D-printed model to assist the surgery. Digital impression taken after healing was used to fabricate the customized abutment and superstructure.

The digital workflow for fabricating implant prosthesis is easier than fabricating restoration for natural teeth. For the latter, the crown margin must be scanned precisely, whereas with implants, after connecting a digital impression coping or scan body on the implant, only the shape of the scan body needs to be accurately captured; the margin between the abutment and superstructure is accurately aligned by the computer. When forming an occlusal relationship in the implant case, the implant restoration should be fabricated to minimize interference in lateral movement. A digital impression (Trios) was obtained for the fabrication of an implant superstructure in a 56-year-old male patient with overdeveloped masseter muscles. To ensure the patient was guided to centric occlusion when taking an optical impression of the buccal bite, the scan was performed with the occlusal point marked by articulating paper. Because a color intraoral scanner was used, the occlusal point appeared on the occlusal surface in a colored display mode. By comparing the pattern of occlusal point distribution and the markings of the distance of the computer-generated occlusal alignment by buccal bite, it was determined that both data indicated the same occlusal points; otherwise, the positional adjustment handle could have been used to finely adjust the relation between the maxilla and mandible. The articulator function can be used by aligning the maxilla and mandible on the occlusal plane of a virtual articulator. In the present case, group-function occlusion with a large premolar cusp inclination was identified and the area with early contact by implant prosthesis during eccentric movement was adjusted in the CAD software to allow fabrication of prosthesis with minimal lateral pressure (**Figure 8**).

Figure 8.
The color function of the digital intraoral scanner was used to compare the marked occlusal points and computer-generated occlusal alignment in testing the accuracy of occlusal registration. A virtual articulator was used to adjust the cusp angle in a patient with an overdeveloped masseter muscle to ensure that excessive lateral force was not exerted on the implant.

4. Use of digital impression data, classified according to the need for modeling

When a digital impression is obtained via an intraoral scanner, the outcome is 3D data consisting of a set of triangles or polygons, which are the smallest units that form a plane. The data are imported to dental CAD S/W to design the prosthesis and the final product is obtained through the CAM process, but because the scanned data cannot be physically handled, consideration should be given as to whether a separate model should be built for any additional work. Producing a working model of the digital impression usually involves CNC milling or 3D printing.

The methods for using the digital impression data from an intraoral scanner can be divided into three types depending on whether production of a model is needed (**Figure 9**). First is the model-free production method, in which only the prosthesis is fabricated and the process of model production is omitted; this is employed when only a small area is being restored. Second is the method by which a model is built to complete the final form of the prosthesis or for fitting. As the reference for porcelain firing, a model may be used to test the fit of a prosthesis against opposing and adjacent teeth. The last method is the active use of a separately built model. It is used in cases for direct wax-up to reproduce the fine details of the 3D characteristics of anterior teeth surfaces. The prosthesis would be fabricated by the traditional method of direct wax-up on the die of the model built by milling or 3D printing.

4.1 Model-free workflow

With the gradual expansion of the clinical application of monolithic zirconia or full-contour zirconia crown without the build-up of feldspathic porcelain, the clinical technique of model-free prosthesis fabrication using an intraoral scanner

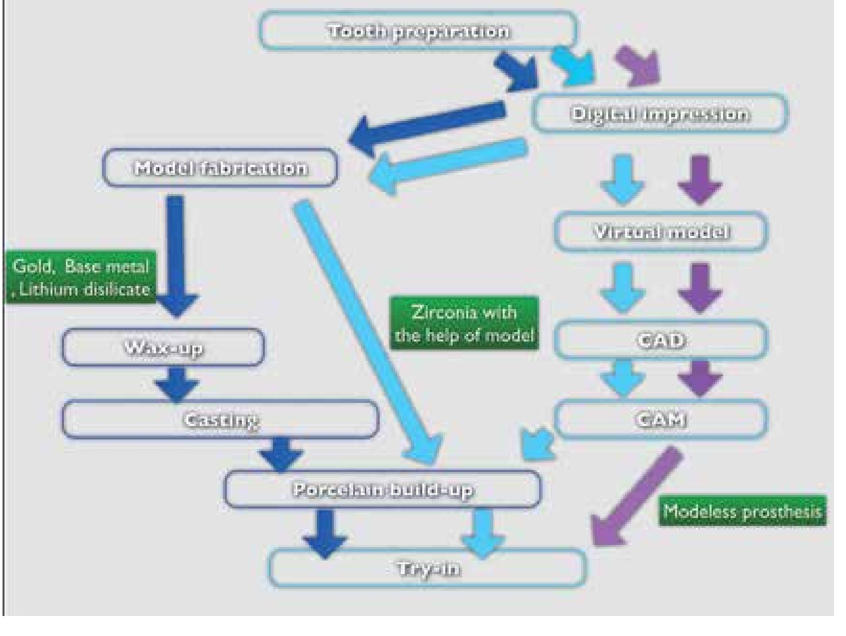

Figure 9.
Methods for using a digital impression data from an intraoral scanner according to the need for modeling.

has gained broader use (**Figure 10**). Formerly, the lack of knowledge concerning coloration techniques and shallow penetration of coloring material resulted in unsatisfactory esthetic outcomes due to the opaque-white color of zirconia appearing after occlusal adjustment. However, as a result of deeper color penetration and the introduction of more transparent, naturalistic zirconia blocks, this problem has practically disappeared.

There are differences in tooth preparation design depending on the clinician, especially axial-wall taper and rounding of the abutment teeth edges. Therefore, when starting the model-free clinical process for the first time, it is necessary to adjust the values of the parameters for the inner surface of zirconia crown inputted into the prosthesis design S/W to match the teeth preparation tendencies of the clinician. When the internal gap of restorations fabricated by inputting several different CAD parameters were measured, the restorations fabricated by means of the model-free workflow exhibited a marginal gap that was slightly higher than 100 microns, which would be within the clinically allowable range as reported by McLean et al. The line angle and occlusal surface showed large internal gaps, just like zirconia crowns fabricated by in-lab process using a model scanner. In addition, the margins of the zirconia crowns fabricated via the model-free workflow showed a slightly over-contoured tendency as compared to the conventional emergence profile. In such a case, plaque retention below the margin occurs more readily and the likelihood of gingival inflammation increases as well. The reasons for over-contouring in the margins of the crown are as follows: Because the thin portion of the zirconia crown margin may break off during fabrication if the amount of abutment tooth preparation is insufficient, the crown is milled to leave enough thickness so that the thickness can be adjusted manually relative to the die of the stone cast. However, in the model-free concept, the work is based on intraoral scan data. The traditional silicon impression material can express the contour of the tooth root on the stone die to a certain degree by penetrating up to 5 mm below the margin of the abutment tooth; whereas the intraoral-scanner method is based on an imaging technique, and the undercut below the margin does not scan very well. Therefore, there is no root contour that can be referenced during the CAD process, and the root

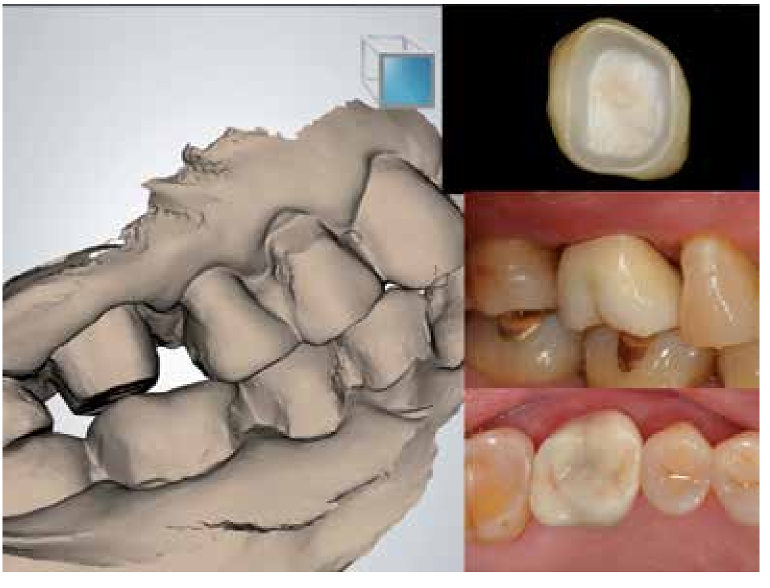

Figure 10.
Case of fabrication of prosthesis based on model-free concept.

contour is insufficiently reproduced in the die milled/printed, limiting the ability to refine the marginal area of the zirconia crown that was fabricated with extra thickness. In other words, the root contour below the margin of the impression body must be registered to a certain degree to allow for a prosthetic design with a naturalistic emergence profile; however, the digital impression taken with an intraoral scanner does not register enough of the area below the margin when compared with the traditional silicon impression. Therefore, when using a model-free workflow with an intraoral scanner, clinicians need to consider these points and reaching an understanding with the laboratory.

4.2 Cases when a model is needed

The cases that require a physical model are those that require additional finishing work after the fabrication of coping. In such cases, the intraoral scan data may be sent separately to the model production center. Both CNC milling and rapid prototyping can be applied to model production. The milling process uses a polyurethane block with wear resistance against subsequent wax-up work, while rapid prototyping by 3D printing also uses comparable resin as the material. As 3D printers have become readily available for in-office use and are supplied with model building materials, many dental offices are starting to print models in the office.

Model production requires the scanned data to be processed. An example using Model builder (3shape, Denmark) S/W is as follows (**Figure 11**). First, any area unrelated to the area being restored or the movable tissue away from the alveolar bone are deleted to reduce the overall size of and optimize the data. By setting the position of the scanned dental arch to match the occlusal plane of the virtual articulator and checking the occlusal relationship automatically aligned by the lateral bite scan acquired together with the upper and lower jaw scan, the position of the

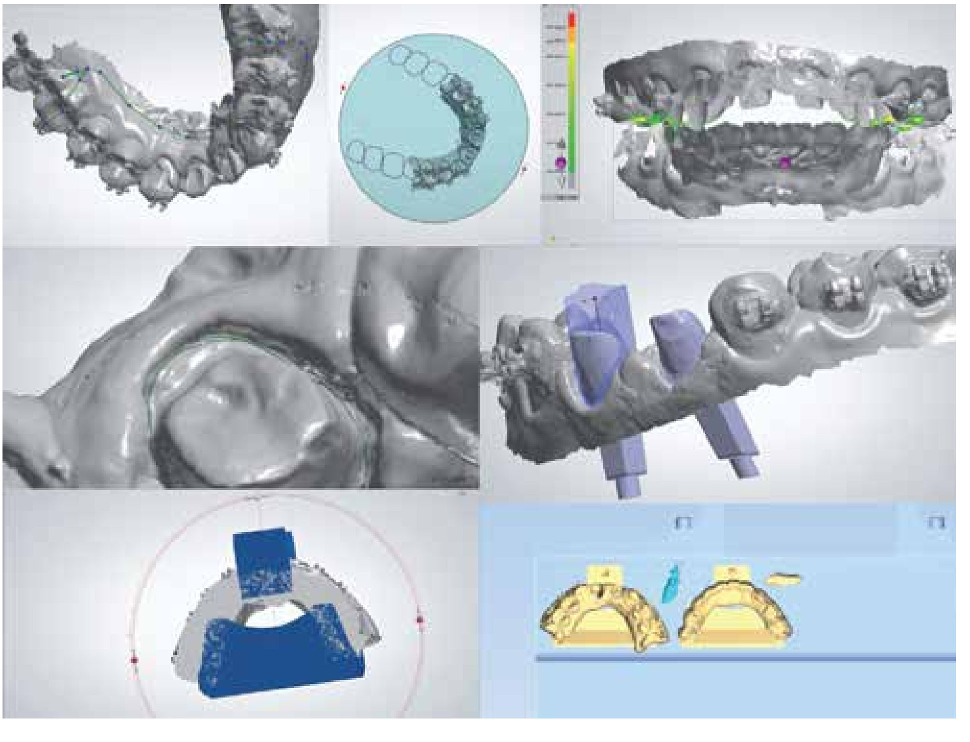

Figure 11.
Processing of intraoral scan data for model building.

upper and lower jaw is carefully revised on CAD when necessary. After setting the margin line of abutment teeth to separate the die portion from the other parts of the model, the path of insertion and removal is determined to match the direction of adjacent teeth. After aligning the finished model to appear in the center of the simple articulator, sending data to a 3D printer or milling machine for output can yield the shape of the simple articulator, while also reproducing the occlusion that the patient had at the time of intraoral scanning by physically holding the upper and lower jaw models in hand. Although limited in scope, such model building S/W helps to inform the revision of data, which can be used to modify the impression of the abutment teeth in the marginal area that may not have been acquired well. Such work may be performed in cases where the patient cannot return to the dental office and the prosthesis must be fabricated immediately. Data are not perfect immediately after the acquisition of digital impression with an intraoral scanner, and the data must therefore be reviewed before the patient returns to home to make sure that important parts, including the margins, have been imaged properly.

Models built by milling or printing are usually used in cases of porcelain fused to zirconia restoration. It is also used in implant restoration cases where the implant prosthesis is generally fabricated as an abutment-superstructure dual structure. If pretreatment is needed to check a model due to the range of the prosthesis being too large, a model can be built separately and used accordingly.

4.3 Use of traditional methods

In addition to the indirect purpose of using a model to check the fit of prostheses fabricated by CAD/CAM process, it can be used for wax-up on top of a die model.

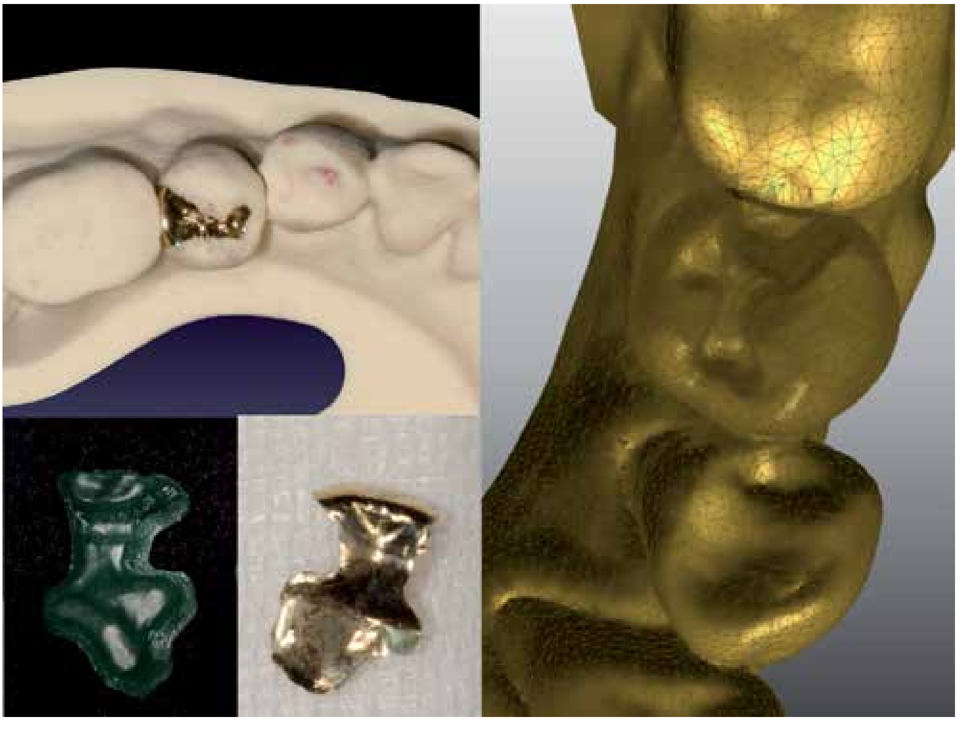

Figure 12.
For crowns and bridges fabricated on a model built by intraoral scan data, restorations by traditional methods can be fabricated, but there are limitations in expressing narrow bevels in gold inlays due to insufficient resolution.

The reason for its separate categorization is because only the steps from impression taking to model building are performed digitally, while all subsequent processes follow a traditional workflow. Although most of the processes in restorative dentistry are performed digitally, there are still limitations in expressing the fine surface texture of the anterior teeth by milling or printing, and materials used for milling have limitations in expressing various color characteristics. To overcome these deficiencies, the final restoration can be fabricated by a wax-up of the die. If optical impression of the marginal area was properly obtained, a favorable clinical outcome may be expected. However, in cases that require the reproduction of very thin bevels in the margins, such as with gold inlay, it should be avoided: there are limitations to the availability of ultra-high-resolution scanners that can register such fine details of tooth shape or equipment and mill or print fine details at the inlay-bevel level. Moreover, a meta-analysis by Chochlidakis et al. that reviewed the fit of 339 digital and analog restorations reported that digitally fabricated restorations showed a comparable level of marginal fit as restorations fabricated by traditional methods. However, restorations fabricated by the model-free method using intraoral scan data were more accurate than those fabricated on 3D printed or milled model. This is because equipment errors that may occur during the model building process can be disregarded when compared to the model-free workflow; moreover, solutions to this problem can continually be improved as the precision of the equipment advances in the future (**Figure 12**) [1].

5. Considerations for comparative assessment of intraoral scanners

With the emergence of 3D digital scanners, existing impression acquisition technique is being replaced with digital technology. While intraoral scanners, various CAD S/W, milling machines, and 3D printers are needed to create a digital office, acquiring such expensive equipment can be a burden for private clinics. Therefore, it is prudent for clinicians to obtain various details concerning the accuracy and clinical efficacy of intraoral scanners before investing. The points that dentists should consider when selecting an intraoral scanner can be categorized as shown in the figure (**Figure 13**). The accuracy of an intraoral scanner can be determined by assessing the following aspects: resolution, accuracy of the range of the quadrant arch, accuracy of the range of the full arch, accuracy of the range of the individual tooth, and accuracy of color reproduction. For hardware characteristics of an intraoral scanner, the following factors can be assessed: scanner-wand size, the need for a scan spray or powder, the maximum depth of field recognized by the scanner, anti-fog function, and durability based on the sterilization of the scanner tip. With respect to clinical efficacy, the following should be considered for actual clinical application: ease-of-operating of the S/W interface; ability to find the scan position or direction during mid-scan; whether the scanned data can be exported to a standard format of an .stl file; the learning curve for assuring the accuracy of data, shortening the scan time, and becoming familiar with the intraoral scanner; and cost-effectiveness of the equipment.

5.1 Accuracy

The most important criterion for an intraoral scanner is accuracy. Currently, the accuracy of intraoral scanners is sufficient in cases limited to a quadrant, but caution should be taken with long restorations that extend beyond the median line. In a questionnaire surveying preferences in digital impression acquisition after using two types of intraoral scanners (image stitching versus video sequencing), the responses were predominantly positive regardless of the type of intraoral scanner.

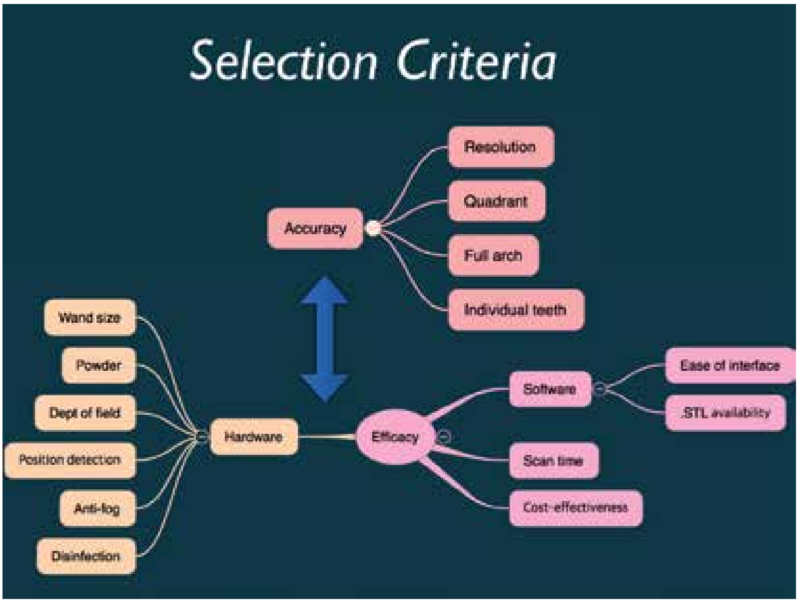

Figure 13.
Criteria that dentists should consider when selecting an intraoral scanner.

Such preference was even higher in the age group that was more familiar with digital technology; based on such high preference, it is expected that intraoral scanners will be increasingly implemented and actively used in dentistry [2].

An intraoral scanner collects intraoral images of the patient and recombines the images as a 3D object. While this procedure is being executed, the computer limits the data resolution in the scan S/W. A polygon formed by three points serves as a criterion for assessing the resolution of scanned data. The higher the number of polygons, the higher the resolution. Assessment has been performed by using intraoral scanners to scan the upper central incisor abutment tooth that was prepared for crown. When the polygons that formed the surface of the model were counted, different scanner systems showed variance in the number of polygons to express the same tooth shape (from 6000 to 400,000 polygons). A higher number of polygons is more favorable for expressing sharp lines in the tooth margin. In addition to the number of polygons, the shape of the polygons is also important. Images with uniformly-sized equilateral triangles lead to faster processing speeds during CAD work and a lower probability of errors than do those with many long, needle-like polygons found between more regular planes (**Figure 14**) [3].

When fabricating a fixed dental prosthesis for natural teeth by using an intraoral scanner, the ability to scan by differentiating the fine gap between the gingiva and abutment tooth margin is an important feature. When gaps ranging in size between 50 and 1000 microns were created and scanned with intraoral scanners, scanners evinced different levels of performance: some were unable to differentiate gaps smaller than 300 microns, whereas others were able to detect 50-micron gaps. Accordingly, it is advantageous to use the latter in clinical practice.

When the jig presented in ISO 12836 was scanned to test the performance of various intraoral scanners, most intraoral scanners, excluding True definition (3 M LAVA), could not scan geometric shapes. Intraoral scanners have a limited optical window size and can perform a scan only when the target object fills more than half of the optical window. Moreover, the algorithm in the system automatically deletes the image when nearby oral tissues, such as the lips or tongue, are included in the scan, which often prevents the intraoral scanners from producing

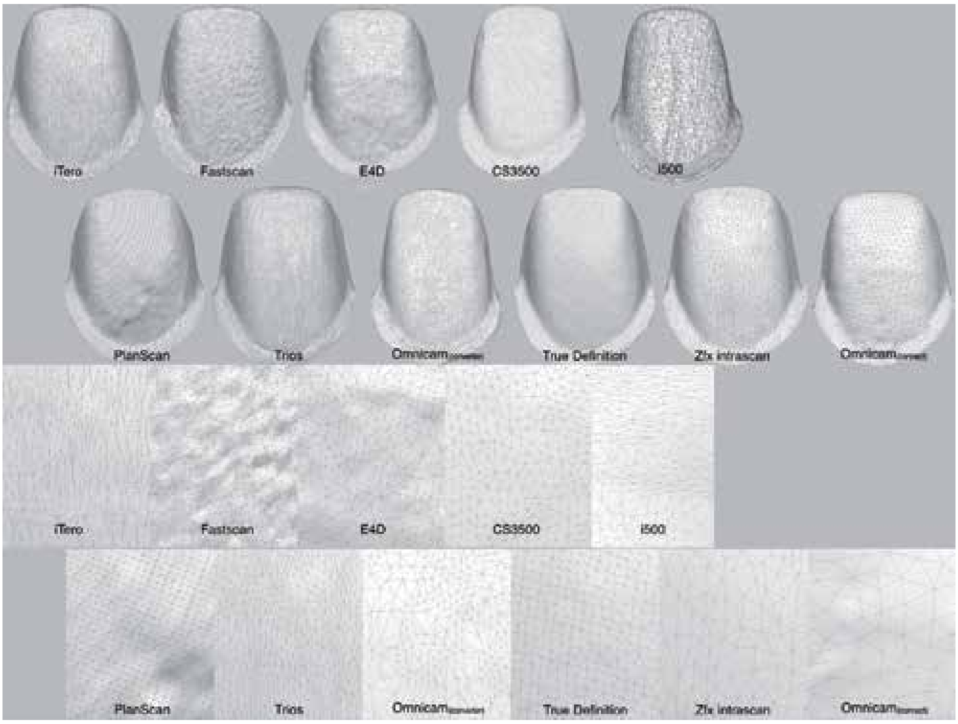

Figure 14.
Data acquired with various intraoral scanners for the same abutment tooth. It can be confirmed that the size, shape, and distribution of the polygons vary according to the systems.

normal images of repetitive shapes that can be easily aligned. Accordingly, it may be unreasonable to use ISO 12836 as the testing standard for intraoral scanners.

In addition, trueness and precision should be calculated and considered together when assessing the accuracy of intraoral scanners; when the archer shot all arrows inside the bull's eye, both the trueness and precision is good; if the arrows are concentrated in other areas, such as the second target, precision may be good, but trueness would be poor; if the arrows are observed in the third target, trueness may be good, but precision would be poor; when the arrows are spread apart, both trueness and precision would be poor.

Crowns, 3-unit fixed dental prostheses, and inlay abutment teeth were fabricated using a commercial high-precision milling machine to assess the intraoral scan data for the unilateral dental arch. Compared to the E4D Dentist and Zfx Intrascan, Fastscan, iTero, and Trios intraoral scanners evinced better accuracy in most cases. Systems that use active triangulation among their scan principles or spray powder showed high accuracy, while there were no statistically significant differences between image stitching and video sequencing methods [4].

When anterior teeth, including canines, are scanned, arch form distortion may occur. Patzelt et al. mentioned widening and narrowing of the molar region, while a clinical trial by Park et al. observed molar distortion and changes in anterior incisal length [5, 6]. Ender and Mehl reported that accuracy may vary according to scanning strategies, while Ahn et al. reported that differences in accuracy were found when the scan direction and order were changed when scanning a complete-arch orthodontic model [7, 8]. For this same reason, intraoral scanner companies specify that the recommended scanning strategy should be used during the whole dentition scan.

Because of the limited optical window size, image recombination errors in the scan S/W of intraoral scanners may occur under certain conditions. When mandibular anterior teeth with the same size and shape were aligned by varying the interdental gap and scanned using iTero and Trios, both systems detected arch form distortion; the variance where the distortion occurred appeared to be due to differences in the optical system and recombination algorithm of the systems [9].

Park et al. reported on the accuracy of full dentition scan data when a bracket was installed for orthodontic treatment. Each intraoral scanner varied in its ability to reproduce different types of brackets with various materials. In particular, lingual orthodontics with the bracket mounted on the lingual side achieved lower accuracy than did buccal orthodontics; the extent of decrease in accuracy varied among intraoral scanners [10]. Fortunately, there was very little difference in accuracy based on the presence or absence of orthodontic wire. However, even in this, differences in performance among intraoral scanner systems were found [11].

Park et al. reported on the complete-arch scan accuracy of nine different intraoral scanners. A high-precision industrial scanner with an accuracy of <10 microns and over 100,000 scan points was used as the reference in assessing the trueness and precision of intraoral scanners. Various cases of abutment teeth that can be encountered in clinical practice were fabricated precisely with the industrial milling machine to build phantom models that were used in the study. For qualitative assessment on the differences in trueness, comparison of color maps showed that the distortion of the full dentition was not significant in most recently introduced intraoral scanner systems, whereas systems that have been on the market relatively longer showed poorer accuracy; this finding may have been due to differences in the optical system and 3D recombination function of their respective S/W. When the polygon pattern was analyzed at the same position and angle for a more detailed comparison, the results showed that the intraoral structure was differentially expressed. Similar to the deformation of the impression body observed when an impression is obtained using a traditional silicon impression material, such scan errors can also occur in a digital impression body. Therefore, it is recommended that clinicians should consider the possibility of such an error and personally check the important areas in completing the scan. While some intraoral scanner systems were able to accurately reproduce intraoral conditions, other systems were not able to do so. Fortunately, most of the recently introduced systems show clear and accurate results [3].

One of the most common questions concerning the use of an intraoral scanner is how much occlusal adjustment is needed when a crown is fabricated. Although it varies by system, occlusion between the upper and lower jaw is in most cases registered by scanning the buccal bite under maximum intercuspation. For comparative assessment on the accuracy of a buccal bite scan, metal cylinders with various lengths were used to create a space between the teeth on the measurement side, and a buccal bite scan from the opposite side was acquired. Here, occlusal reproducibility of the intraoral scanners was measured by comparing the amount of interdental spacing on the measurement side against the reference scan. The bite was registered higher or lower depending on the system, and the extent of such differences varied. Therefore, when using intraoral scanners in clinical practice, it would be necessary to assess the accuracy of a buccal bite scan [12]. When the buccal bite-scan accuracy was compared in implant cases, the results also showed differences according to the systems used [13]. In addition to such variance in the performance of the intraoral scanners themselves, it should also be kept in mind that the final prosthesis height may become inaccurate if the patient does not bite down with centric occlusion.

Depending on the principle on which the intraoral scanner system is based, the scan distance or depth recognized by the scanner can vary. When the abutment tooth is too long or the gap from adjacent teeth is too narrow, the intraoral scanner must be lowered and rotated to the side to scan that area, since the focal length is limited. In doing so, if the S/W that superimposes the data has poor performance, it is difficult to obtain an image of the target area with a single scan and the scan time may be prolonged. When six different intraoral scanner systems were used to acquire digital impressions of various inlay cavities with narrow and deep cavities to assess the depth performance of intraoral scanners, the results showed that the pulpal floor depths of the cavities were different than the actual depths. If the cavity is shallow, the fabricated inlay is also thin and gap is filled with cement, which increases the possibility of inlay fracture after long-term use. If the cavity is deep, inlay with high occlusion is fabricated, which requires more time for occlusal adjustment. The bottom surface and lower corners of the inlay cavity box that are difficult to approach with an intraoral scanner on account of their being too close to adjacent teeth show various patterns of scan errors depending on the intraoral scanner system.

Recently introduced intraoral scanners feature polychrome systems that display mapping of natural color texture. Therefore, whether the color information obtained from intraoral scanning can replace the tooth shade selection process when restoring anterior teeth is worth consideration. Color differences in images obtained from digital intraoral scans and clinical photography were compared against a reference obtained from spectrophotometer to investigate clinical applicability. The color shade information obtained from intraoral scan data tended to be slightly bluer than the actual color shade and would thus be problematic to use as absolute data. However, since it is useful as a color map of teeth with white lines or brown spots, it would be best employed as a supplement [14].

5.2 Hardware

Each intraoral scanner system has its own proprietary operating principle, as each manufacturer has registered patents for the operating principles of its own intraoral scanners; thus, the products are developed to not infringe on existing patents. Moreover, the scanner wands also have different shapes and sizes; recently, there has been a trend towards producing lighter scanners with smaller scanner tips that has led to reduced patient discomfort and shorter scanning times. Indeed, intraoral scanners with scanner tips about the size of a handpiece used for tooth preparation—or even smaller—have been introduced. However, as the size of the optical window becomes smaller, more images need to be stitched together; moreover, because the amount of surrounding structures needed for stitching decreases, the accuracy of the scanned data decreases. S/W development would therefore need to develop in tandem with the decrease in hardware size to use small intraoral scanners with high accuracy that can easily scan the distal surface of most posterior molars in clinical practice.

The need for spray or powder during scanning is another H/W characteristic related to the performance of intraoral scanners. Powder is used to increase the recognition rate of scanners by balancing the reflective conditions of materials with different surface reflectance rates. Nedelcu et al. reported that applying an excessive amount of powder does not have a statistically significantly negative effect on accuracy [15]. However, in actual clinical practice, it is difficult to apply the powder to hard-to-reach areas inside the narrow oral cavity, such as the distal surface of most posterior molars. Moreover, in cases wherein it is difficult to control how much powder is being applied due to the applicator used, an excessive amount of powder may accumulate to cause the scan data to appear differently than the actual condition. In healthy young adults with active saliva secretion, if saliva covers the area where powder was applied, powder may clump together to affect the scan results. Since there are reports indicating that fine and ultrafine particles contained in scanning spray may be harmful to respiratory tract, using powder-free intraoral scanner system is recommended whenever possible. Meanwhile, many manufacturers are introducing intraoral scanners that do not need scanning spray and can overcome the problem of scattered reflection.

The maximum depth of field recognized by the scanner has a significant influence on the intraoral scanning process. If the range of depth is shorter, systems that terminate the scan if the surface being scanned does not maintain a certain distance from the scanner tip require close attention and are difficult to use, meaning the learning curve becomes very steep. If the scan can be performed without any problem when the scanner tip touches the teeth or even when the distance becomes longer, then the clinical efficacy of such an intraoral scanner would increase.

Because the scanner tip of intraoral scanners consists of a mirror and a glass window, fogging can occur on the optical window when the tip is suddenly inserted into the oral cavity; this can interfere with the scan and slow the scanning speed. To prevent fogging, the scanner tip is heated with a heat wire or air is blown into it. Systems with a heat wire require a waiting time to allow the scanner tip to be sufficiently heated, while systems with airflow can dry the inside of the oral cavity. Lastly, most intraoral scanners feature the ability of changing the scanner tip for sterilization, and thus, durability of the scanner tip based on EO gas or autoclave sterilization must be considered. Small cracks may form on the glass window after 20–30 rounds of sterilization, and images acquired thereafter would contain noise, which may slow the scanning speed and require replacement of the scanner tip.

5.3 Clinical efficacy

With good S/W support, the intraoral scanner system can offer convenience and high efficacy in clinical practice. With respect to such clinical efficacy, ease-of-operation of the graphic user interface (GUI) of the scan S/W itself can be helpful. Input of patient and abutment tooth information must not be unwieldy, and the system must allow all necessary information to be inputted without omission. Further, it must be easy to send the data obtained after completion of scanning to the design center. Recently, many intraoral scanner manufacturers allow for the uploading of data to a cloud server and the notification of the design center. Since scanned data can be viewed in a 3D orientation via a web browser or a separate application, it has become possible to relay work instructions while viewing the data when consulting with the lab technician –not only in the office but also while on the move.

Systems with an excellent S/W recombination algorithm feature a higher clinical efficacy. During digital impression acquisition, additional scans are needed for areas that were not scanned properly. When applying the intraoral scanner to the areas that require additional scanning, and scanning of surrounding area is re-initiated, systems should be able to find the area again quickly and accurately. In particular, when scanning natural tooth abutment, it is effective to scan the mesial and distal surfaces by rotating the intraoral scanner to a 90° angle from the dentition. Systems that reinitiate the scan by automatically recognizing the rotated direction after the scanning is halted are more convenient to use in clinical practice. This is possible if the system has a function that recognizes the change in angle within the algorithm that searches and matches previously scanned data. In addition, intraoral scanners that use video sequencing add data in real-time, and thus, when moving tissues that contact the teeth, the area around the teeth may become messy and contain unwanted data that require deletion from the screen and necessitate the performance of additional scans. To address this issue, systems with an "undo" function that regresses a few seconds to a point prior to the displacement of the tissues being added to the scanned data have been introduced.

Recently, dental CAD S/W with a variety of functions have been introduced; however, whether the operator can export scan data from the intraoral scan system easily as the standard format of .stl is an important point to consider before using them. Many manufacturers of intraoral scanner systems emphasize that their scanners are based on an open architecture. However, there were cases of reduced resolution in which only low-resolution data marred by an unexpected decrease in the number of polygons in the data were exported; inverted surface shell in which the scanned data were converted to an inverted form, rendering them unusable for CAD work; and loss of bite information in which the positional relationships of the maxillary and mandibular data returned to their original points and data on the inter-arch relationship were lost.

Lastly, the learning time required to become familiar with handling the intraoral scanner to shorten the intraoral scanning time and increasing the accuracy of scanned data should be considered. Kim et al. reported the results from an in vivo study that investigated the learning curve for intraoral scanners. A total of 29 volunteers who wished to learn how to use an intraoral scanner participated in 10 sessions of digital impression acquisition lessons over 4 days. Because the volunteers had used an intraoral scanner for the first time, they made several errors, including widening of the posterior arch, lengthening of anterior length, and not combining two or more dental arch fragments together. If the problem could not be resolved by the erase and add scan function, the scan was started again from the beginning. Based on these results, the learning curve was derived. The analysis divided the participants into the groups that used intraoral scanners with image stitching versus video sequencing; both groups showed that adequate learning was achieved after repeated practice. The former achieved a higher learning rate since scanning was difficult, but even after 10 rounds of lessons, scan time was longer than that of the video-sequencing group [16].

Lim et al. reported on the assessment of changes in data accuracy after repeated practice scanning compete-arch maxillary and mandibular dentition using the two of the same intraoral scanners. In the group that used the difficult image-stitching method, repeated practice influenced the accuracy of scanned data, indicating that practice must be invested to use the method in clinical practice. The group using video sequencing demonstrated a weak learning effect with better accuracy of scanned data relative to the other group. This group was not influenced by clinical experience or the oral structure of the patient, suggesting that video sequencing can be used more easily in clinical practice [6].

6. Conclusions

Although intraoral scanners have many advantages, there are many unresolved issues with respect to impression acquisition time. Unlike implant cases where the margin between the customized abutment and zirconia crown is arbitrarily set by a computer, impressions cannot be acquired accurately if the margin is not exposed in natural teeth cases. Therefore, the same processes as conventional technique, such as the insertion of a gingival cord and controlling saliva and bleeding, must be performed. Unlike the traditional method of waiting after injecting the impression material, images must be acquired continuously with an intraoral scanner, which necessitates supervision and, hence, more man-hours. As a method for overcoming such limitations, the dentist and dental hygienist must cooperate. Following the insertion of the gingival cord or while the patient is waiting, the dental hygienist can acquire a preliminary scan. Subsequently, the dentist can delete data from the abutment tooth area and perform a precision scan in only that area. By utilizing functions that are only possible by digital method, such limitations can thus be overcome. In addition, the development of next-generation intraoral scanners that feature the application of ultrasonography and optical coherence tomography is underway. If a digital impression can be acquired easily without having to control bleeding via the gingival cord immediately after tooth preparation, then intraoral scanners will become an essential tool to all dental offices.

Compared to the traditional prosthesis fabrication process, the advantages of intraoral scanners and CAD/CAM include the simplification of the work process; qualitative standardization of the lab process; effective and informed communication between dentist and lab technician; improved work efficiency; and permanent preservation of patient data that can be re-used when necessary. Indeed, there was a case in which a patient for whom we fabricated a partial denture contacted us to tell us that the denture has been lost. This was a case that underwent digital workflow, and the metal framework design was therefore stored in the hospital database. Accordingly, the metal frame was 3D printed and cast to prepare in advance of the patient's arrival to the hospital. As a result, the denture-fabrication time was halved.

Today, intraoral scanner technology has become more advanced, its interface has become more convenient, and the price of equipment has become more reasonable. As a result, it is becoming increasingly used in dentistry. Because there are many advantages that can be gained should clinical dentistry adopt a digital workflow, there is a bright future for digital dentistry.

Acknowledgements

This work was supported by the Yonsei University College of Dentistry (6-2018-0012).

Conflict of interest

None.

Author details

Ji-Man Park* and June-Sung Shim
Yonsei University College of Dentistry, Seoul, South Korea

*Address all correspondence to: jimarn@yuhs.ac

References

[1] Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis. The Journal of Prosthetic Dentistry. 2016;**116**(2):184-190.e12

[2] Park HR, Park JM, Chun YS, Lee KN, Kim M. Changes in views on digital intraoral scanners among dental hygienists after training in digital impression taking. BMC Oral Health. 2015;**15**(1):151

[3] Kim JY, Park JM, Shim JS. Accuracy of 9 intraoral scanners for complete-arch image acquisition: Qualitative and quantitative evaluation. The Journal of Prosthetic Dentistry. 2018 (Epub ahead of print)

[4] Park JM. Comparative analysis on reproducibility among 5 intraoral scanners: Sectional analysis according to restoration type and preparation outline form. Journal of Advanced Prosthodontics. 2016;**8**(6):354-362

[5] Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clinical Oral Investigations. 2014;**18**(6):1687-1694. DOI: 10.1007/s00784-013-1132-y

[6] Lim JH, Park JM, Kim M, Heo SJ, Myung JY. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. The Journal of Prosthetic Dentistry. 2018;**119**:225-232

[7] Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. International Journal of Computerized Dentistry. 2013;**16**(1):11-21

[8] Anh JW, Park JM, Chun YS, Kim M, Kim M. A comparison of the precision of three-dimensional images acquired by 2 digital intraoral scanners: Effects of tooth irregularity and scanning direction. Korean Journal of Orthodontics. 2016;**46**(1):3-12

[9] Chun J, Tahk JH, Chun YS, Park JM, Kim M. Analysis on the accuracy of intraoral scanners: The effects of mandibular anterior interdental space. Applied Sciences. 2017;**7**(7):719-725

[10] Park JM, Choi SA, Myung JY, Chun YS, Kim M. Impact of orthodontic brackets on the intraoral scan data accuracy. BioMed Research International. 2016;**2016**:5075182. DOI: 10.1155/2016/5075182

[11] Jung YR, Park JM, Chun YS, Lee KN, Kim M. Accuracy of four different digital intraoral scanners: Effects of the presence of orthodontic brackets and wire. International Journal of Computerized Dentistry. 2016;**19**(3):203-215

[12] Park JM, Jeon J, Heo SJ. Accuracy comparison of buccal interocclusal record scans by five intraoral scanners. Journal of Dental Rehabilitation and Applied Science. 2018;**34**(1):17-31

[13] Park DH, Park JM, Choi JW, Kang ES, Bae EB, Jeon YC, et al. Accuracy of several implant bite registration techniques: An in-vitro pilot study. Journal of Advanced Prosthodontics. 2017;**9**(5):341-349

[14] Yoon HI, Bae JW, Park JM, Chun YS, Kim MA, Kim M. A study on possibility of clinical application for color measurements of shade guides using an intraoral digital scanner. Journal of Prosthodontics. 2018;**27**(7):670-675. DOI: 10.1111/jopr.12559

[15] Nedelcu RG, Persson AS. Scanning accuracy and precision in 4 intraoral scanners: An in vitro comparison based on 3-dimensional analysis.

The Journal of Prosthetic Dentistry. 2014;**112**(6):1461-1471

[16] Kim J, Park JM, Kim M, Heo SJ, Shin IH, Kim M. Comparison of experience curves between two 3-dimensional intraoral scanners. The Journal of Prosthetic Dentistry. 2016;**116**(2):221-230

Chapter 4

Role of Computer Technology in Changing Smile

Swapnil B. Shankargouda, Preena Sidhu and Sonica Miyyapuram

Abstract

In the ever changing complex society, where success has become a mantra for both young and old, facial appearance that includes smile, plays a pivotal role. Among many attractive components in a person's face, smile reflects the persona of an individual. In the present day next gen age, science in unison with technology and techniques which are rapidly getting ingrained into day to day dental practice, has changed the perception of healthy smile by more effective and less invasive approach. In this scenario, the onus lies on the dentist to give that perfectionist touch to a customised smile using computer aided software and hardware apparatus, and to avail the best state of the art material, equipment and techniques. Hence, it is imperative for us to understand and inculcate the role of modern cutting edge computer-aided technologies used in designing and changing the smile of an individual.

Keywords: dental technology, smile designing, digital impressions, digital radiography, CAD/CAM technology, smile makeover

1. Introduction

Technology plays a significant role in most areas of life and the dental field is not any exception. Patients and doctors have each benefited from the advancements and inventions in dentistry which supply trendy solutions to ancient dental issues that may be performed in an exceedingly economical and effective manner. The health of the mouth and body will improve with every new technology. Remember, good health starts within the mouth. As best said by Darwin, it seems that we have a tendency to all smile within the same language. Today, smile is definitely the foremost recognized expression that necessitates a natural study pattern that is pleasing to others. So, our responsibility as smile designers and dental specialists is to face this new challenge and acquire the abilities to spot and design numerous smile patterns, integrated by diagnostic, clinical and laboratory procedures. So, let us find out how technology can help us achieve this challenge. Dentists are incorporating the following high-tech tools into their practices.

2. Extra oral video camera

It permits having a close record of the patient's face while moving and talking. It will record the patient in numerous moods and gestures. It is an audiovisual record of the patient's ideas, preferences, expectations and complaints as well as the dentist's suggestions and explanations of various treatment options. Totally, different smiles and profiles are often applied to the patient's face, and therefore, the patient is often given the chance to settle on the simplest smile style [1].

3. Intraoral video camera

More or less, an intraoral camera is a little camcorder that takes a radiographic X-ray of the outside of the gum or tooth. The intraoral camera is nothing more than a larger than average pen and in spite of the fact that the use of the camera changes depending upon the model-type, this picture taking gadget is normally furnished with an disposable plastic sleeve for each new patient. While at the same time seeing a screen, the dental specialist tenderly moves the camera into the patient's mouth with the goal that pictures can be taken from an assortment of points.

First utilized in the mid 1990s, the intraoral camera is yet a moderately new bit of dental gear. Not very far in the past, just a bunch of practitioners inside the dental network utilized this little camera to take photos of the teeth and gums. Today, utilization of the intraoral camera is far reaching. For those dental practitioners who do utilize this gadget, the intraoral camera has been, and keeps on being, incredibly convenient both in diagnosing dental conditions, for example, tooth decay and fractured teeth and in instructing the patient. Most intraoral cameras are no greater than the size of a thumbnail, yet give unparalleled analytic capabilities. Intra oral examination of each point with the littlest subtleties can be seen as close as 2 mm from the tooth. With it we can diagnose certain conditions and plan treatment alternatives significantly more precisely than with representations, mirrors and radiographs [1].

4. Computer or voice activated data

Utilizing voice enacted innovation; dental specialists can report their discoveries by talking into the amplifier that are connected to a PC which has been "prepared" to perceive a restricted vocabulary. The PC at that point stores the data and even illustrations (identified with grin), so different methods can be examined with the patient.

5. Digital radiography

X-rays were discovered in 1895. Since then film has been the first medium for capturing, displaying, and storing pictures. Digital radiography is the latest advancement in dental imaging. RADIO-VISIOGRAPHY, the primary direct digital imaging system was invented by Dr. Frances Mouyens. It was manufactured by Trophy Radiologie (Vincennes, France) in 1984 and later described within the US dental literature in 1989. Compared to ancient X-rays, digital radiography may be a filmless technique that uses up to 90% less radiation. It additionally provides prime quality, digitally encoded data that may be adjusted electronically to alter contrast density or to amplify specific areas. By using digital radiography, buccolingual width of the jaws as well as the location of anatomic features such as the mandibular canal and the maxillary sinus can be determined which is useful while placing an implant in the esthetic position. Now-a-days manufacturers promote digital radiography system and video camera in one unit, i.e., single hand piece which can be convenient to be used [2].

6. Direct digital imaging

Various components are required for direct computerized picture generation. These parts incorporate a X-ray beam source, an electronic sensor, an advanced interface card, a PC with a analog to digital converter (ADC), a screen, monitor, and a printer. Normally, frameworks are PC based with a 486 or higher processor, 640 kb inside memory furnished with a SVGA illustrations card, and a high-goals screen (1024 × 768 pixels). Direct advanced sensors are either a charge-coupled device (CCD) or complementary metal oxide semiconductor active pixel sensor (CMOS-APS). At the point when an X-ray beam collaborates with the screen material, light photons are produced, identified, and put away by CCD. Direct sensor CCD clusters catch the picture specifically. CMOS sensors have a few points of interest including structure joining, low power prerequisites, manufacturability, and minimal effort.

6.1 Advantages of CCDs

1. Decrease in exposure.
2. No processing chemicals required.
3. Real-time and instant images generated and shown.
4. Improvement in image.
5. Patient education.
6. Convenient storage capacity.

6.2 Disadvantages of CCDs

1. Sensor thickness and rigidity are more.
2. Goals are decreased.
3. Initial framework cost is more.
4. Life expectancy of sensor is unknown.
5. Control of infection is difficult.

6.3 DICOM standard

It is an acronym for digital imaging and communications in medicine. Medical radiologists found that many of their imaging systems could not communicate with each other. Most manufacturers had their own proprietary software and file types that were not compatible with those of other manufacturers. Now dentistry is beginning to recognize the DICOM 3.0 standard which is helpful for insurance companies in maintaining records and assessing claim estimation. (e.g., dental record, voice activated charting) [2].

6.4 DentaScan

A specialized type of CT or "CAT" scan which is performed on a conventional CT scanner. It is produced and licensed by General Electric (GE) and is performed only on "state-of-the-art" GE CT machines. It produces a highly detailed cross-sectional image of maxilla or mandible, which is then analyzed to evaluate dental implant sites.

6.4.1 Features

1. Axial or helical CT data is reformatted to display four images per screen for the mandible and maxilla.

2. Oblique images permit visual inspection of cortical bone and alveolar nerve for optimal implant placement.

3. Multiple (5 or 9) panorex images demonstrate pathology when needed, along with the nerve canal.

4. Oblique and panorex reformations are cross-referenced to each other and to the original CT images.

5. User selectable distance between oblique reformations (from 1 to 10 mm).

6.4.2 Advantages

1. Allows high resolution (1 mm) computerized images.

2. Allows precise measurements of the potential dental implant sites.

3. Access the mineralization or density of the involved bone site.

4. Produces a very low dose of X-ray exposure with negligible adverse effects.

7. WAND local anesthesia system-computer controlled device

A newly described maxillary nerve block injection which was first reported during development of a computer controlled local anesthetic delivery (CCLAD) system.

7.1 Components of WAND

1. Local anesthesia cartridge.

2. Microtubing.

3. Disposable handle.

4. Leur-lock needle.

5. Foot control.

WAND is activated by foot control. On activation, automatic delivery of solution at precise pressure and volume ratios takes place. Steady and continuous rate of flow is maintained. Solution can be deposited even if resiliency is encountered, resulting in effective and comfortable injection [3].

8. Comfort control syringe

It is an electronic, pre-set local delivery system of local anesthesia that administers the local anesthetic agent in a slower, more controlled and more reliable way than a conventional manual injection. The comfort control syringe has a two-stage system of delivery of local anesthetic system. The infusion starts at a moderate rate to limit the inconvenience related with quick infusion. Following 10 s, comfort control syringe naturally increases the infusion rate for the system that has been chosen [3].

9. Electronic dental anesthesia (EDA)

9.1 Indications

1. Patients with needle phobia.
2. When local anesthesia is ineffective.
3. Patient allergic to local anesthesia.

9.2 Contraindications

1. Patients with cardiac pacemakers.
2. Patients with neurological disorders.
3. Pregnant female patients.
4. Patients having dental phobias.

9.3 Mechanism of action

At low frequency (2 Hz) TENS produces increase in blood levels of serotonin and β endorphins. These possess analgesic actions which benefit to patient undergoing restorative, crown and bridge or periodontal procedures. EDA produce excellent soft tissue anesthesia and may be used when multiple palatal infiltrations are given. EDA can reverse effect of local anesthesia by maximizing vasodilation and muscle contraction [3].

9.3.1 Advantages

1. There is no need for needle.
2. There is no need for injection of drugs.
3. There is no residual anesthetic effect.
4. There is residual analgesic effect for hours.

9.3.2 Disadvantages

1. It is expensive due to high cost of the unit.
2. It is technique sensitive, so special training is necessary.

3. It has a learning curve.

4. Presence of intraoral electrodes forms the weak link in entire system.

10. Computer aided design/computer assisted milling technology

Computer aided design/CAM is an abbreviation for computer-aided design/computer-aided manufacturing. It has been utilized for a considerable length of time in the manufacturing business to deliver precise apparatuses, parts and autos, CAD/CAM innovation has been progressively inducted into dentistry in the course of recent years.

Computer aided design/CAM technologies and metal free zirconia materials are utilized by dental specialists and dental research facilities to give patients processed artistic crowns, facade, onlays, inlays and fixed partial dentures. As the materials and innovations accessible for CAD/CAM dentistry have improved throughout the years, so too have the rehabilitation efforts that patients can get from this type of advanced dentistry. The present CAD/CAM rehabilitation efforts are better-fitting, progressively solid and increasingly normal looking (multi-shaded and translucent, like regular teeth) than recently machined prosthesis.

10.1 In-office and dental laboratory CAD/CAM options

Dental CAD/CAM innovation is accessible for dental practices and dental labs, empowering dental practitioners and their staff (or a research facility expert) to structure rehabilitation efforts on a PC screen. The CAD/CAM PC shows a 3-D custom picture of the virtually built tooth or teeth acquired by carefully scanning the tooth/teeth preparations with an optical scanner. On the other hand, the 3-D images can be acquired by scanning a custom made model got from conventional impressions of the tooth/teeth arrangements.

The dental practitioner or dental lab professional at that point utilizes those 3-D pictures and CAD programming to draw and plan the prosthesis. The duration of time it takes for a dental specialist, in-office lab professional or lab expert to rehabilitate an oral structure differs, dependent on aptitude, experience, and difficulty level of the case and treatment rendered. A few cases could take minutes, while others could require a half-hour or a greater amount of configuration time to guarantee quality.

When the last rehabilitation step is planned, the crown, inlay, onlay, facade or fixed partial denture, is processed from a single rigid block of fired material in a processing chamber. The rehabilitation at that point can be altered with stains and coatings to make an increasingly regular look, before being casted in a casting furnace and after that completed and cleaned.

10.2 Benefits of CAD/CAM dentistry

Research suggests that today's milled CAD/CAM restorations are stronger than those milled from earlier materials. They also are less likely to fracture. One of the advantages of CAD/CAM technology is that, same day dentistry may be a treatment option for patients. CAD/CAM dental technologies such as CEREC in-office or the E4D dentist system can be used to make an inlay, onlay, crown or veneer restoration in a single appointment, while you wait.

10.3 Special considerations for CAD/CAM dentistry

Computer aided design/computer assisted manufacturing is not a replacement for the preciseness and ability of a dental specialist or dental rehabilitation expert.

Dental specialists must be precise in preparing the tooth; both the dental specialist and dental laboratory technician must be precise when making the impression digitally and planning the prosthesis.

Similarly, the precision and ability with which they plan a prosthesis is vital, especially since the internal and marginal fit is important to avoid future tooth deterioration [4].

11. Digital shade selection guides

Shade selection is a procedure which provides patients an aesthetic restoration that harmoniously blends to the patient's existing dentition. Different shade guides are available in the market: Vita Classic, Vita System 3D-Master, Chromascop and custom or specific chroma and value guides. Clinicians often end up with compromised restoration because they encounter difficulty in interpreting a multi-layered structure of varying thickness, opacities and optical surface characteristics.

There are limitations of shade guides as we fail to account for the variability found in natural teeth, e.g., fluorescence, opalescence, translucency, enamel thickness, and objectivity.

The effects of surface texture on light reflection are different. The characterizations must be recorded and duplicated in the final restorations. The use of technology with different devices in shade selection has eliminated subjectivity of choosing and the use of photography to communicate shades and characterizations has improved the selection process. The property of light source to influence color of objects is called "color rendition." There are special lights that are color corrected to emit light with a more uniform distribution of color that can be utilized [5].

11.1 Instrument shade selection

11.1.1 Colorimeters

It consists of a detector, signal conditioner and software with four photodiodes along with filters. It has an inability to maintain adequate sensitivity at low light levels. It is inferior to scanning devices like spectrophotometers [6]; for example, Chromascan (Sterngold, Connecticut).

11.1.2 Spectrophotometers

It mainly includes three specific components.

- A standard D65 light source.
- Means to direct the light source to an object and receive the reflected light from the object.
- A spectrometer that provides the most accurate color measurements by determining the intensity of the received light as a function of wavelength [6].

11.2 Shofu ShadeEye NCC

The ShadeEye NCC Dental Chroma Meter produces a total formula to coordinate the shade for a porcelain crown. It will accommodate a few shade guide systems, including its exclusive Vitapan 3D-Master, Chromascop, Biodent, etc. The base unit can create a printout, or can download it to a PC. On the PC, one can utilize the Shade Eye Viewer programming to record the whole patient's shade data which would then be able to be messaged to the laboratory alongside computerized photos of the teeth.

Shofu has 3 mm distance across hand held contact probe with focus at recipient and illuminator at periphery. To match standard observers collect light, color filters are used, which are transmitted to the docking unit, which analyze and present the shade in Vitapan classical designation Shofu ShadeEye NCC [6].

11.3 Vita Easyshade

It is a hand held spectrophotometer with a 5 mm contact test tip and a 20 kW halogen tungsten light D65.The base unit is associated with hand piece through monocoil fiber optic link. It has three spectrometers in the hand piece to quantify inside dissipated light and a PC handling unit to dissect the spectrometer information, decide a shade match to current Vita Classical and 3D shades and yield and show the outcomes [7].

11.4 Shadepilot

It takes into account absolutely exact assessment of spectral information, unaffected by light sources in the medical procedure or other encompassing light. It creates accuracy through correspondence and the highlights incorporate

1. Innovative: as it provides recommendation for enamel and dentin powders veneering.

2. Communicative: as it uses smart communication services for data transmission such as E-Mail, text notes and voice messaging.

3. Accurate: as it compares with the initial measurement of the natural tooth against the finished restoration.

4. Simple: professional assessment of the patient's shade can be done in less than 1 min.

5. Analytical: analysis and administration can be done on PC.

6. Free: there is no interference of ambient light and shades can be matched under all light conditions.

7. Mobile: can be used to measure the shade of the patient anywhere as there are no inconvenient cables attached.

8. Modern: as it uses latest technology to transfer images and data like USB, WLAN, etc.

9. Fast: as analysis of measured data can be done instantaneously.

10. Safe: as optimum measurements of the patient can be taken by angling at the patient.

11.5 Evaluation of the spectral image

11.5.1 Triple-zone measurement

You can request an analysis of the three zones—cervical, body and incisal. Select the zone yourself and analyze individually, accurately and routinely.

11.5.2 Single tone

The basic analysis by Shadepilot gives you an average tooth shade, allowing you to determine the precise area of analysis yourself.

11.5.3 Shade map

The proposed shade map consequently investigates each shade subtlety of the tooth for you. From this, it can determine important subtleties explicitly for the individual tooth layering.

11.5.4 Translucence

Shadepilot can furnish you in a noteworthy route with translucency data determined from the reflected light range.

11.5.5 Comparison

Assesses the pictures to look at the distinction in shading when treatment (tooth bleaching) or between the characteristic tooth and the crown.

11.5.6 Patient data bank

Stores and controls all your deliberate shades. This information, as a picture, alongside all other patient information is accessible for a longer period at whatever point required.

11.5.7 Printing

Other than electronic viewing, this enables patient information to be printed off with all applicable investigation pictures and to pass on or document information [6].

12. Lasers

The dental laser utilizes a light emission instead of surgical blade to perform fragile gum surgical procedure and crown lengthening procedure/gingivectomy and gingivoplasty. Lasers give reduced inconvenience and at times, a suture free alternative for the treatment of tumors, mouth blisters, crown lengthening procedure, caries removal, correction of gummy smile, dental fillings, tongue tie correction and improvements of speech impediment, nerve recovery for damaged nerves and veins and scars. Lasers may likewise be utilized inside the treatment of certain dental conditions like disorders of sleep, certain cases of temporomandibular joint disorders and tooth sensitivity. This is a truly energizing space of advancement in dental technologies. Lasers utilize light-weight devices as their method of operation, bringing about an abbreviated and practically effortless mending period.

The advantages of this method are:

1. Hemorrhage control that provides a clean and dry operative field to provide a wonderful visibility of the operative field.

2. The operating time is decreased and thus reduces the postoperative swelling, scarring and pain [7].

13. Abrasive technology

Although abrasive technology does not replace the dental drill for filling teeth, it often provides an alternative. Working much like a precise miniature sandblaster, this instrument gently sprays away decayed tooth structure using a microscopically fine powder called alpha alumina, a nontoxic ingredient that is also used in whitening toothpastes. Because abrasive technology produces virtually no heat or vibration, it can usually be used without anesthetic injections. Abrasive technology frequently uncovers "veins of decay" that are hidden beneath the "stain pockets" of active tooth destruction that sometimes cannot even be detected by X-rays. It is utilized in any quadrant for any depth of decay while not damaging the healthy tooth structure. It is also useful during repairs of existing composite or porcelain restorations. Serving as an alternative to a traditional dental drill, an air-abrasion system is primarily used to treat small cavities, preserving healthy tooth structure without the use of a local anesthetic. These high tech tools open up a whole new world of possibilities and allow you to achieve the smile you have always wanted [8].

14. Digital impressions

With the advent of the digital impression system, the requirement for conventional dental impressions may in the long run be a relic of days gone by. Digital impressions utilize computerized innovation to make a dental prosthesis design on a PC, with no impression trays or dental impression material included.

On the contrary, digital impressions have omitted the uneasiness and discomfort regularly associated with dental impressions. When the tooth is prepared, it takes minutes for the dental practitioner to record the prepared tooth and make a virtual dental prosthesis directly on the PC screen. The final image of the virtual prosthesis is messaged to a laboratory technician to set up the shape, who thus sends it to a dental laboratory to fabricate/mill the final prosthesis. Digital impressions facilitates for the impressions to be sent to the dental lab straightforwardly, bringing about a shorter processing and fabrication time to create the dental prosthesis.

There are numerous advantages to utilizing the digital impressions system. Digital impressions commonly mean less choking/gagging, shorter dental appointments and a decreased tendency for error as related with conventional dental impressions. There is a decreased tendency for remaking the entire impression due to saliva or food debris contamination due to digital impressions as compared to conventional dental impressions and thus increasing the quality and efficacy with which the prosthesis is fabricated.

Not only does the exactness and accuracy of the digital impression addresses the dental issues related to conventional dental impression, it additionally reduces the work load for the dental practitioner, who might not need to reshape the dental crown once getting it from the dental lab.

There are a few disadvantages to the digital impression system. Most digital impression system have been intended to make permanent prosthesis, so utilizing them to partial and complete dentures is not feasible—for the time being. As digital impression systems are additionally an expensive unit to buy for any dental office, the expense might be passed on to the patients.

In any case, dental practitioners who do use a digital impression system are undoubtedly inspired by the innovation. Patients love the solace and comfort of it, as well. While numerous dental specialists are finding the upsides of this best in class dental innovation, it presently cannot seem to get on at most dental workplaces [9, 10].

15. Rapid prototyping

Rapid prototyping (RP)—alludes to programmed development of mechanical models from graphical PC information. Rapid prototyping is a kind of computer assisted milling/manufacturing (CAM) and is one of the parts of rapid and fast manufacturing of prosthesis.

Amid the late 1980s, the incubation of rapid prototyping system offered new potential outcomes for demonstrating additional oral and maxillofacial deformities. Principally used for the aeronautical and automobile industry to reduce the time required for planning and development of delicate and intricate model parts, it works on the standard of depositing material in layers or cuts to develop a model instead of shaping a model from a strong block of material. Thus, fabricating an accurate prosthesis by replicating all the inner geometry,as opposed to simply the external surface forms,compared to conventional dental prosthesis fabrication.

15.1 Two primary strategies for rapid prototyping

1. Additive—broadly utilized.

2. Subtractive—less successful.

15.2 Commercially used in variety of ways like

1. Stereolithography.

2. Fused deposition modeling.

3. Inkjets.

4. Three-dimensional printing.

5. Selective laser sintering.

6. Laminated object manufacturing.

7. Laser engineered net shaping.

15.3 Stereolithography

Stereolithography was the most essential foremost prototyping innovation to be created during the 1980's and is the procedure that is most commonly used to produce stereolithographic anatomic (SLA) models for medical procedure. The CAD model of the part to be made is cut into a progression of two-dimensional cuts. This information is utilized to control a beam of laser that draws each cut of the model on the outside of a tank of sap.

The photosensitive resin is immediately restored to a solid where the beam of laser strikes. At the beginning of the process, underneath the surface of the liquid resin, a "slice" of thickness of one 0.25 mm platform is positioned over it. On the completion of the first layer, it descends to cover the top of the model with resin to give way for the next layer to be formed. Thus, the model is built from the base up as the platform descends [11, 12].

15.3.1 Building of model

Local polymerization of the liquid is stimulated when the laser beam is drawn onto the surface of the resin. The object borders are solidified at first followed by the internal parts on coming in contact with the laser beam. On polymerization of the layer, the elevated platform moves down to a pre-defined distance of 0.1–0.5 mm layer thickness, with the model submerged in the resin liquid bath. The resin is leveled out as the surface is smoothened by the sweeper. Thus, a new layer of liquid is spread over the hardened layer followed by continuation of the drawing, thus building the model layer by layer.

During the building process, supporting structures (supports) during the process of production must be provided in order to prevent the sagging of the overhanging and isolated part. Finishing of the completed objects is done by draining the excess liquid resin, followed by removal of the supports and curing of the surfaces of the objects using ultraviolet floodlights. Production of a model may last up to 1 day, depending upon the data set resolution, model complexity and the total number of slices.

15.3.2 Advantages

1. Ability to make right prostheses, which helps the restorative outcome and shortens the usable time.

2. No roam for human error.

3. There is no limit on designing of complex mathematic designs.

4. Accurate and symmetrical.

5. Biocompatibility.

Throughout the last 23 years, the CEREC framework has advanced into a predictable method for reestablishing undesirable or disfigured teeth, mistreatment computer-aided design/computer assisted manufacture (CAD/CAM) technology. This CAD/CAM unit, which can manufacture onlays, inlays, 7/8 crowns, ¾ crowns and dental veneers, can allow the professional to restore the tooth with a permanent indirect restoration within one appointment.

The portable mobile unit comprises of three parts: a little camera, a video display screen and a three-dimensional shaping rotation machine.

The CAD/CAM CEREC system has evolved from the:

- CEREC-1, which fictitious solely marginally fitting single and twin surface ceramic inlays.
- CEREC-2, which showed advances in computing, upgraded code and distended type of grinding technique.
- CEREC-3, that may style well-fitting inlays, onlays, crowns, veneers, etc., in an exceedingly single visit.

The CEREC-3 technique involves:

1. Mouth preparation.
2. Powdering.
3. Scanning.

15.3.3 Advantages of the CEREC system

1. It is a single appointment procedure.
2. Impression is not required.
3. There is reduced marginal gap.
4. Glorious sprucing characteristics.
5. There is improved esthetics.
6. Necessity for minimal tooth reduction.
7. Allows to achieve higher dental medicine health.
8. Strength of the tooth is enhanced due to secured restorations.
9. Preparation, fabrication, cementation and sprucing is generally accomplished in 1–1½ hours.

The newest inclusion of the CEREC system is that the CEREC 3D, that provides a flexible, comparatively easy technique for fabricating esthetic restorations chair side while not involving a dental laboratory. The newest system, CEREC 3D (Sirona, Charlotte, NC), has distended on the ideas of PC imaging by utilizing three-dimensional viewing capabilities [11, 12].

15.3.4 Technique: fabrication using an optical impression

This impression can be accomplished in a single visit, eliminating the need for an elastomeric impression, an interim restoration, and payment of a laboratory fee.

The restoration is designed and carved from a solid block of porcelain or composite. These blocks are available in an assortment of shades that can be custom-stained and glazed. After the optical impression is made, restorations are designed on the computer using one of two modes, correlation or dental database. Correlation utilizes a preoperative optical impression of a wax-up of the unprepared tooth, while dental database utilizes the software's virtual library of tooth morphology to create the anatomy and contours of the restoration. The prepared tooth is captured in a single optical impression, along with as many of the adjacent teeth as possible. Multiple optical impressions are possible for quadrant dentistry. From this impression, a "Virtual model" is created on the screen. To create proper occlusion more accurately, both modes can utilize an additional optical impression of a bite registration and create an antagonist tooth model.

15.3.5 Features

The 3D feature of the software allows the model to rotate 360° in every plane to create a virtual die. An alignment tool is visible on the screen to help reorient the image after rotation. The software also displays a view window on the screen that makes arrow icons available and allows the operator to view the preparation and subsequent restoration from six predefined views: occlusal, cervical, mesial, distal, buccal, and lingual. After creating a virtual die, the next step is to outline the margin line on the die. In CEREC 3D, the margins are created automatically by the software, reducing the chance of operator error. The software makes this a user-friendly process through an automatic margin finder. The ability to view the die from any angle allows the dentist to correct the outline more accurately. Once the dentist is satisfied with the margin line, the software will design the restoration and place it on the die for viewing. The contact tightness should be evaluated and adjusted by clicking on the contact button, which is also displayed in the window. The purple line represents the height of contour, while the red, yellow, green, and blue areas all identify different degree of contact tightness [12].

16. Nanotechnology

Nanotechnology is a field of the amalgamation of applied science with technology. The word nano originated from the Greek word "dwarf." In 1959, Richard Feynman, a Nobel Prize winning physicist, was the first to elaborate the concept of nanotechnology in a lecture titled, "There's plenty of room at the bottom." From that point forward, nanotechnology has discovered use in a multitude of uses including dental analysis, material and therapeutics. It is not going to be long, when nanodentistry will prevail with regards to keeping up close ideal oral wellbeing through the guide of nanorobotics, nanomaterials, and biotechnology.

An expert in the field of nanotechnology, Prof. Keric E Dexler, was the first to term nanotechnology, which is the manipulation of matter on the atomic and molecular levels [13].

16.1 Current applications of nanodentistry

1. Endodontic nanocomposites, e.g., 3 M™ ESPE™ Filtek™ Supreme Plus.

2. Prosthetic nanocomposite denture teeth.

3. Periodontal plasma laser application.

4. Prosthetic nanoimpression materials.

5. Restorative nanofilled bonding agents, e.g., G-Bond.

6. Prosthetic dental implants.

7. Restorative nanofilled light-curing glass ionomer.

16.2 New treatment opportunities in nanodentistry may include

1. Major tooth repair.

2. Tooth renaturalization.

3. Hypersensitivity cure.

4. Orthodontic nanorobots.

5. Dental durability and cosmetics.

6. Nanorobotic dentifrice (dentifrobots).

7. Tooth repositioning.

8. Durability and appearance.

9. Inducing anesthesia.

10. Local drug delivery.

11. Molecular monitoring.

17. Digital smile designing [DSD]

DSD is another new innovation in the field of esthetic dentistry that has been acquainted with the universe of restorative dentistry lately. DSD programs are utilized for objective esthetic examination and virtual treatment planning by altering photos and additionally scanning models of patients jaws. Most of the smile designing softwares explicit for dental practice appear to disregard facial style parameters and focus on esthetic and dentogingival concepts.

Adobe Photoshop and Keynote were not specifically made for digital smile designing; be that as it may, these two softwares characterize, measure and adjust the most elevated number of dentofacial esthetic components. Photoshop and Keynote fulfill facial examination criteria; in this manner, they could be utilized for investigation of complex cases that require treatment other than restorations alone and where orthodontic or surgical intervention are to be considered. In spite of the fact that there are numerous digital smile designing software programs accessible explicitly for dental specialists, it is conceivable to utilize Photoshop and Keynote to make and show patients the proposed dental restorative treatment. Their significant downside is that a moderate to cutting edge level of preparation is required by the dental specialist so as to use the product capacities during the time spent for esthetic smile designing. A number of specialists have utilized Photoshop for DSD and decided the essential options to be utilized in the diagnosis. These incorporate editable teeth moulds, division of the observation grids, techniques of measurement, rules for the initial wax mock-up and permanent restoration prediction. The competency of Keynote in DSD has additionally been depicted in the literature. Like Photoshop, Keynote gives the capacity to characterize reference lines and line angles and acquire the required restoration.

Computer aided design/computer assisted machining companies, for example, Sirona have improved the esthetic highlights of the anterior teeth restoration in their software programming. Whenever assessed, CEREC SW 4.2 could build a 3-D computerized model of the patient's face to permit control of the considerable number of measurements of carefully planned esthetic rehabilitation procedures including functional analysis of the articulated models. DSD programs consolidate digital innovation to the smile designing procedures and can be utilized as digital tools for analysis, treatment plan evaluation, and correspondence with the patient and dental laboratory technician that can formulate a predictable dental treatment outcome. Be that as it may, not all the DSD programs accessible today give a similar competency to complete examination of the dentofacial esthetic components. Despite the fact that this is a standout amongst the most imperative components to be viewed as while picking a DSD program, different factors, for example, usability, case documentation capacity, cost, time proficiency, orderly advanced work process and association, and similarity of the program with CAD/CAM or other computerized softwares may likewise impact the dentists choice [14].

18. Conclusion

The knowledge and practice of yesteryears may not assist the dental specialist with achieving perfection later on. The ability of replacing a tooth esthetically and functionally is demanding and there is positively no excuse for error. Use of magnification/amplification using dental loupes will become a necessity to achieve better visibility and provide state of the art restorations which would not be possible as accurately with the naked eye.

A dental practitioner will be compelled to give better impressions of the prepared tooth to suit CAD/CAM designed prosthesis fabrication. Lengthy and technique sensitive laboratory procedures will be replaced by CAD/CAM methods and we should overhaul our knowledge and technological constraints by updating ourselves to suit the cutting edge innovation.

Imaging innovation will likewise experience incredible change. Volumetric radiographic technique will progress towards becoming in-office and will assist the clinician with diagnosing difficult temporo-mandibular disorders. Intuitive softwares like Simplant will simplify the diagnostic and surgical placement of the dental implants. The number and size of implants necessary to rehabilitate the edentulous space can be pictured well in advance prior to the implant surgery depending upon the computed tomography (CT) images taken in the in-office machine. Investigating and diagnosing the occlusal abnormalities using computed tomography images will no longer be a difficult task. Nanotechnology based dental materials and products will be a common affair, particularly for restorations and dental impressions. Dental specialists may observe caries-free teeth and bioengineered tooth substitutes in the near future. Therefore, dental specialists will never be able to ignore the fast yet ever changing technologies, which may disruptively affect the present system.

The future belongs to those who tell the best tales about the future; at the end of the day, just inventive masterminds will get a chance to contribute towards future expert needs. Dental specialists ought to wind up visionaries of an actually improved future like the (CEOs) of the information technology (IT) area who envision a land with astute iceboxes, thinking shoes, self-governing vehicles and online doctors.

Conflict of interest

None.

Author details

Swapnil B. Shankargouda[1*], Preena Sidhu[2] and Sonica Miyyapuram[3]

1 Department of Prosthodontics and Crown and Bridge, KLE Academy of Higher Education and Research, VK Institute of Dental Sciences, Belgaum, Karnataka, India

2 Faculty of Dentistry, SEGi University, Kota Damansara, Malaysia

3 BDS, KLE VK Institute of Dental Sciences, Belgaum, Karnataka, India

*Address all correspondence to: swapnil.shankargouda@gmail.com

References

[1] Intraoral Camera Information [Internet]. Available from: https://www.1800dentist.com/about-dentistry/intraoral-camera

[2] Parks T, Williamson G. Digital radiography: An overview. The Journal of Contemporary Dental Practice. 2002;**3**(4):23-39

[3] Virtually Painless Injections—Electronic Anesthesia [Internet]. Available from: http://www.ryedaledental.co.uk/electronic-anesthesia.htm

[4] Shaping Dentistry with CAD/CAM Technology [Internet]. Available from: https://www.yourdentistryguide.com/cad-cam-tech

[5] Ho CCK. Shade selection. Australasian Dental Practice. 2007;**1**:116-119

[6] Vintage Shade Guide PN 9620 AND PN 9621 [Internet]. Available from: http://www.shofu.com.sg/Shofu-Dental-Materials-Equipment-Instruments-Product-Detail-109-VINTAGE%20SHADE%20GUIDE

[7] Coluzzi D, Convissar R. Lasers in clinical dentistry. Dental Clinics of North America. 2004;**48**(4):10-12

[8] Chandrasekharan Nair K. Marching ahead to the future. The Journal of Indian Prosthodontic Society. 2007;**7**(3):162-165

[9] Bhat AM. Recent advances in the modeling of extraoral defects. The Journal of Indian Prosthodontic Society. 2005;**4**:180-184

[10] Joshi MD, Dange SP, Khalikar AN. Rapid prototyping technology in maxillofacial prosthodontics: Basics and applications. The Journal of Indian Prosthodontic Society. 2006;**6**(4):175-178

[11] Mormann WH. The evolution of the CEREC system. Journal of the American Dental Association (Chicago, IL). 2006;**137**:75

[12] Guest GF. Internet resources for dentistry: Government and medical sites for the dental professional. The Journal of Contemporary Dental Practice. 2000;**1**(2):120-125

[13] Christensen GJ. Prosthodontics is in your future. Journal of the American Dental Association (1939). 2000;**131**(5):671-672

[14] Omar D, Duarte C. The application of parameters for comprehensive smile esthetics by digital smile design programs: A review of literature. The Saudi Dental Journal. 2018;**30**(1):7-12

Chapter 5

Clinical Computing in Dentistry

Aswini Kumar Kar, Prabhu Yuvaraj, Mirna Garhnayak, Shruti Vishal Dev, Purna Chandra Mishra, Tapan Kumar Patro, Loknath Garhnayak, Sonali Perti and Nabagata Ganchoudhury

Abstract

Machines can seldom replace dentists in rightly handling the patients with optimistic human insight, considerations, creative planning and the monitoring of psychological acceptance and comfort experienced by any patient with the rehabilitation done. Intelligent computer related armamentarium with software can still help dental practitioners detect typical medical and dental signs and classify them according to certain rules more effectively. Based on image analysis algorithms, CAD systems can be used to look for signs of any tooth pathology that can be spotted in dental X-ray or cone beam computed tomography (CBCT) images. Applying computer vision algorithms to high-resolution CBCT slices helps to a great extent in diagnosing periapical lesions like granulomas, cysts, etc., and can help creating 3-D model of a root canal that reflects its shape with sufficient precision facilitating an optimum endodontic treatment planning. Hence, computer vision systems are already able to speed up the diagnostic process and provide a valuable second opinion in doubtful cases. This can lead a dentist and the patient thoroughly experience an optimistic acceptance and satisfaction of the treatment done.

Keywords: software, CBCT, clinical computing, computer vision

1. Introduction

The inevitable significance of virtual reality in the practice of dentistry is a result of continuous adherence of public practice with computer based technologies. Research work in the recent decades quoted many innovative and technological advancements introduced in the field of dentistry. Computer technology seems to form the future of dentistry [14]. Today's dental practice shows an evident usage of CAD-CAM of dental appliances and prostheses worldwide. Yet, VR (virtual reality) and AR (augmented reality) techniques are tracking their own significance in learning and working and are still not explored sufficiently. Virtual reality (VR) technologies have a strong impact on research, development, and industrial production.

VR technologies in dentistry will be used to provide better education and training by simulating complex contexts and enhancing procedures that are traditionally limited, such as work with mechanical articulator.

This chapter aims at discussing the computer based technologies including VR and AR simulators, CAD-CAM systems and their multidimensional application in dentistry.

2. Virtual reality technology

In today's reality, current trends of technologies are at optimum acceleration in a wide range. Virtual reality technology is defined as a method by which an environment is three dimensionally simulated or replicated, giving the user a sense of being inside it, controlling it and personally interacting with it [3, 4]. Designing of a new product brings in the significance and wide usage of VR and the incorporation of 3D modelling in it [1]. The field of health care can never be an exception in the usage of VR as its usage is remarkable in the instructions of surgical procedures [14, 36, 39], student training and patient [31, 41] instructions. VR technology has evidences in successful treatment of complex regional pain syndromes [15] and in creating virtual environment [6] to assess behaviour and rehabilitate cognitive and functional abilities in patients with psychological disorders to help in their treatment [17].

3. Features of virtual reality

Two basic features of virtual reality are: (i) immersion and (ii) interaction.

3.1 Immersion

Immersion is the sense of being present in virtual environment. 3D images, sound and other stimuli are created to simulate an environment that surrounds the user and make them feel a physical presence in a non-physical (non-real) world [22, 32]. Depending on the capabilities of various VR systems ranging from fully immersive to non-immersive systems, the degree of user's belief of being present is noted [11].

3.2 Interaction

Interaction is the power of user to modify the virtual environment [32]. This is well understood with a difference felt between 3D movies and virtual environments. VR systems readily facilitates user to interact with the virtual world, move around, see from various angles, reach, touch and reshape it evidently. Head mounted video goggles wired clothing and fibre optic data gloves can help this sort of interaction possibly [33].

4. Types of VR systems

Virtual reality systems are classified into three major groups such as non-immersive, semi-immersive and immersive based on immersion and type of components used in the system [11] (**Figure 1**).

4.1 Immersive VR simulation

Possibility of giving the user the psycho-physical experience of being surrounded completely by virtual computer generated environment (as illustrated in **Figure 2**) is brought by immersive VR simulation using hardware, software and interaction devices. Stereoscopy is a process by which full immersion, i.e., the highest level of immersion is produced by head mounted device that displays 3D images. This process shows two images to user—one per eye—which are combined by brain into single 3D image. Data gloves are other components that enable the person to interact with objects. Pulling the objects, twisting or gripping are best examples and these components may also give

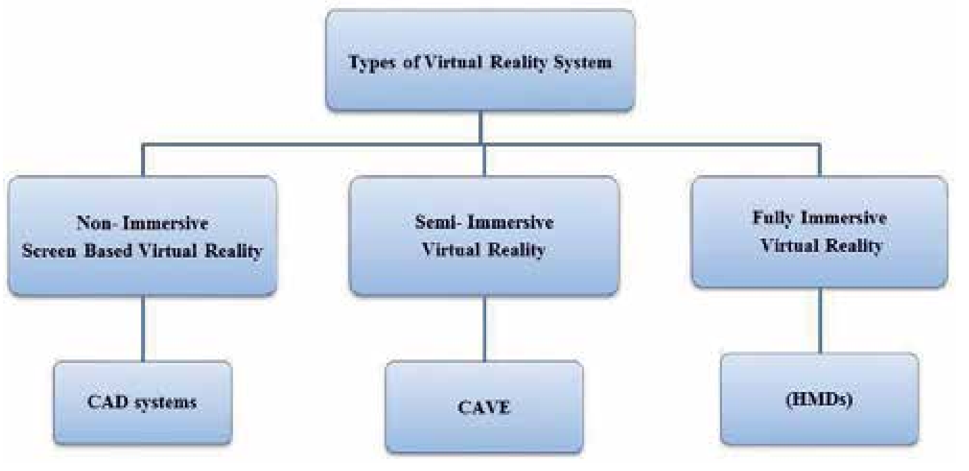

Figure 1.
Types of virtual reality systems [5].

Figure 2.
Immersive virtual reality; head mounted displays (HMD) and data gloves [5].

force feedback to user and it is known as haptic. The tracing devices which can track user's head, hands, fingers, eyes and feet to enable interaction with the virtual world are also on usage. The sense of display and sounds can make the user fully immersive to virtual environment and feel separated from the real world [18, 20].

4.2 Semi-immersive VR simulation

This system makes the user stand in a room with a rear projection wall, down projection floor, tracking sensors and sound devices (as illustrated in **Figure 3**) on walls with speakers at different angles. The user is made to see everything three dimensionally by wearing eye goggles. The system is not considered a fully immersive simulator since the user can still see him or herself. An example of this system is the cave automatic virtual environment [8].

4.3 Non-immersive VR simulation

This system stands as the least expensive and least immersive of all. By incorporating stereo display monitor and glasses, this system helps user to be involved with 3D environment. Designing and CAD systems makes use of this type of simulations and this can be run on a standard desktop computer with mouse or joystick [18] (as illustrated in **Figure 4**).

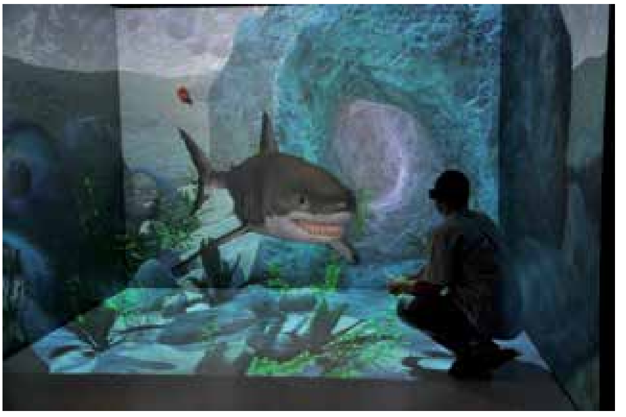

Figure 3.
Semi-immersive virtual reality; cave automatic virtual environment (CAVE) [5].

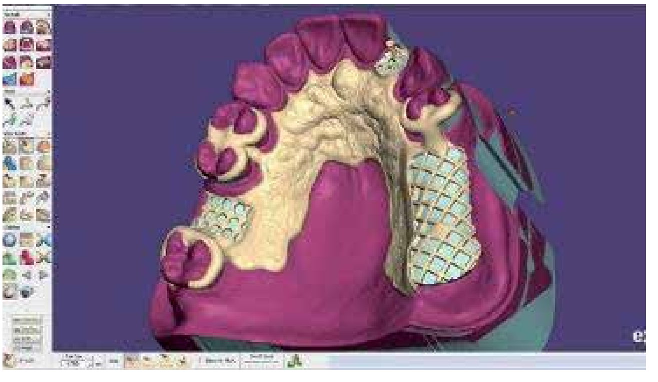

Figure 4.
Computer-aided design system [5].

5. Application of VR in dentistry

Application of VR simulation systems in dentistry is still considered to be a challenge even though its application in different aspects of medical training such as laparoscopic surgery [40], etc., are evident in reality. The difference with dental instruments in type, shape, speed and diversity of oral tissues such as gingiva, multilayer teeth and bone with their own complexity contributes to the reason for difficulty in application of the systems [27].

In the dental virtual reality systems, the operator makes use of the stylus which with the help of worn special goggles, appears as the intended instrument like high or low speed hand piece in 3D displaying stereoscopic monitor, to simulate the tooth reduction [21]. Here, the accurate digitized models of instruments, oral cavity tissues and sophisticated graphic programs for showing reduction of tooth are the factors considered to be mandatory.

Different layers of tooth like enamel, dentin and dental pulp are modelled in VR systems and this helps dental students to avoid unintentional exposure of dental pulp during clinical practice [42]. The haptic devices bring in possibility for the user to feel the force required for each practice (force feedback) and provide a realistic tactile sense and hence the differentiation between various structure or speed of instruments is only possible with the help of haptic devices. These devices paves way for surgeons to touch and feel objects such as surgical tools and human organs in a virtual environment

Concept	Classification	Fully synthetic virtual world	Fully real virtual world	Absolute spatial registration critical	Relative spatial registration critical	Real-time interactivity critical
Augmented reality	Uses computer	No	No	Maybe	Yes	Yes
Virtual reality	Uses computer	Yes	No	No	Yes	Yes

Table 1.
Comparison of virtual reality and augmented reality [5].

to perform procedures like pulling, pushing and cutting of soft and hard tissues with realistic force feedback. Programming of VR simulator to identify errors and assess the quality of performance is an additional advantage. The basis for comparison and assessment is the fact that the experts determine the best performers and errors [12, 13].

6. Augmented reality

In AR, the real environment is not completely suppressed and notably plays a significant role in the process (as shown in **Table 1**), making it contrast to VR simulators. AR refers to super imposition of computer generated graphics of real world scene [7]. Instead of engaging a person in a world that is computer generated, augmented reality aims to add synthetic additives to real world or to a live video of real world [34]. Image guided surgery where real and virtual objects need to be composed, integrated, presented or manipulated simultaneously makes the best use of AR [9]. Wide application of AR is also seen in maxillofacial surgery temporomandibular joint motion analysis, prosthetic surgery and dental implantation [36, 39, 41].

Visualization of deep masked structures is where AR is mainly used in oral and maxillofacial surgery. The surgeon maps the surgical map on the 3D image of the site and considers for any necessary modification before the surgery. In the surgery, the surgeon follows the mapped image overlaid on the surgical site with special glasses during the surgery. Ventures for the development of this system for root canal therapy are on progress. To enhance the training capacity, few systems make use of AR and VR technologies [38].

7. Future of VR and AR in dentistry

Creation of new models for diagnosis and treatment for technically challenging patients can be made possible by the dynamic association of operation on real organ with imaging data. The VR and robotics, as new technologies will have great impact on health care in the near future [19]. This can help experienced surgeons, extending safe limits for more efficient operations [36, 39]. Still there are technological challenges that researchers and developers must face even though VR and AR systems seem to be promising.

8. Dental CAD-CAM systems

Many advanced chair side and laboratory CAD-CAM systems were introduced in the past couple of decades. Data collection, designing and manufacturing has been made easy by CAD-CAM systems. CAD-CAM in dentistry holds its own significance like manufacturing by milling technologies. However, it is not completely true as manufacturing can either be by subtractive (milling) or additive technologies [16, 28] (**Table 2**).

The CAD-CAM systems consists of three components:

1. A digitization tool/scanner that transforms geometry of real world object into digital data to enable processing by a computer.

2. Software for data processing.

3. A technology which manufactures the desired product from the digitized data set [28].

Different types of materials such as porcelain, composite resin and metallic blocks are used in the manufacturing of many fixed prosthetic restorations. Zirconia, which could not be manufactured by conventional methods previously due to technical limitations can also be manufactured now by these systems [30]. The CAD-CAM systems are going to find substantial applications in implant dentistry to manufacture implant supported prostheses, abutments and diagnostic templates [29].

The main benefit of this in dentistry is that the conventional impressions are not needed anymore, which is believed to save dentist's chair time and eliminate a time consuming step [25]. The CAD-CAM techniques and rapid prototyping are widely used in treatment of maxillofacial defects and surgeries [23]. These techniques are also used for designing and manufacturing the metal components of removable partial dentures by 3D printing [10, 35]. Additionally, this helps in collection of 3D data from the patient's cast, determining the path of insertion and designing the shape of components or frameworks digitally. The completed models are stored as stereolithography files, which are later transferred to rapid prototyping models. Finally, metal removable partial dentures are fabricated by selective laser melting techniques [24]. Various factors like orthodontic diagnosis, treatment planning [26] and fabrication of appliances (Invisalign production process) which include submitting of scan or impressions and photographs to the company with doctor's instructions. Making use of CAD-CAM technology these intraoral scans or impressions are used to design accurate 3D digital models for each dental arch after which

Advantages of CAD/CAM systems	**Limitations of CAD/CAM systems**
No need for traditional impressions when intraoral scanners are used	High cost
Chairside fabrication of restorations	Need mastering of technology
Fewer visits	Manual veneering is used most of the time
Needs less manual procedures in laboratory	
Needs less laboratory time	
Easier laboratory procedures	
Good marginal accuracy	
Suitable for materials like zirconia	

Table 2.
Advantages and limitations of CAD/CAM systems [5].

stereolithographic model is fabricated for each step. Then a plastic aligner will be made over each model and the set of aligners are then sent to the practitioner [37].

Determination of impacted maxillary canines and fabrication of occlusal splints are also done with this. Comprehensive visualization and records of the craniofacial complex are important goals in orthodontic imaging which have been conventionally achieved by means of plaster dental casts, photographs and radiographs. However, cone-beam computed tomography (CBCT) has gained considerable acclaim worldwide as a viable tri-dimensional (3D) imaging modality [3].

1. CBCT is a medical image acquisition technique based on a cone-shaped X-ray beam centered on a two-dimensional (2D) detector. The scanning software collects the raw image data and reconstructs them into a 3D data set.

2. Whenever it is necessary to comprise the whole craniofacial region in the study, as in cases of cephalometry analyses, a large field of view (FOV) must be selected, which, according to the American Academy of Oral and Maxillofacial Radiology.

3. Captures a spherical volume diameter or cylinder height >15 cm.

4. However, CAD-CAM additive manufacturing innovations have not been used successfully for a wide range of removable orthodontic appliances [26].

Virtual articulator, a basic tool in the CAD-CAM systems, deals primarily with functional aspects of occlusion and is a core tool in many diagnostic and therapeutic procedures [2] (as shown in **Table 3**). According to GPT 8, an articulator is defined as,

> *"A mechanical instrument that represents the temporomandibular joints and jaws, to which maxillary and mandibular casts may be attached to simulate some or all mandibular movements." There are several articulators available in market today, some are very complex and some are very simple in their use and adjustments. The articulator to be used depends on preference of dentists. The late Carl O. Boucher stated "it must be recognized that the person operating the instrument is more important than the instrument itself. If dentists understand articulators and their deficiencies, they can compensate for their inherent inadequacies."*

Virtual articulators are also called as "software articulators" as they are not concrete but exist only as a computer program. They comprise of virtual condylar and incisal guide planes. Guide planes can be measured precisely using jaw motion analyser or average values are set in the program like average value articulator. The virtual articulators are able to design prostheses kinematically. They are capable of simulating human mandibular movements, by moving digitalized occlusal surfaces against each other and enabling correction of digitalized occlusal surfaces to produce smooth and collision-free movements.

The virtual articulator offers the possibility of significantly reducing the limitations of mechanical articulators, due to a series of advantages: full analysis can be made of static and dynamic occlusion, of the intermaxillary relationships, and of the joint conditions, thanks to dynamic visualization in three dimensions (3D) of the mandible, the maxilla or both, and to the possibility of selecting section planes allowing detailed observation of regions of interest such as for example, the temporomandibular joint. Combined with CAD/CAM technology, this tool offers great potential in planning dental implants, since it affords greater precision and a lesser duration of treatment [14].

	Virtual reality	Augmented reality	CAD/CAM systems
Prosthodontics		Diagnosis and treatment planning for implant placement	Fabrication of crown and bridge frameworks Fabrication of custom made abutments for implants Designing and manufacturing of implant surgical splints Designing and manufacturing RPD metal frameworks Designing complete dentures Virtual articulator which used in many diagnostic and therapeutic procedures
Maxillofacial surgery	Training by performing virtual surgery 3D observation of surgical site	Superimposition of radiograph over the surgical site Implant placement during surgery	Making maxillofacial prosthesis
Orthodontics			Diagnosis and treatment planning Determining the position of impacted maxillary canines
Periodontics	Training of scaling	Diagnosis and treatment of periodontal diseases Differentiating between pathological and normal conditions	
Restorative dentistry	Training tooth preparation		Fabricating indirect restorations

Table 3.
Applications of computer-based technologies in dental aspects [5].

9. Conclusion

Today, designing and manufacturing dental appliances and prostheses makes a significant use of computer based technologies. Still, the simulation systems for instructions or dental skills are the new modalities unexplored and used very by few dental practitioners and schools. These systems are under constant progress and development. Like most of the other new technologies, they are too expensive with more maintenance and repair costs. Computer assisted skill acquisition in conjunction with traditional training on the other hand would enable students to practice repeatedly with constant assessment and for feedback which is rarely possible with resin models. Simulation systems enable the students in surgical field to practice in real mode on virtual subjects. Surgeons can make the best use of visual information on surgical site provided.

DOI: http://dx.doi.org/10.5772/intechopen.81646

Author details

Aswini Kumar Kar[1*], Prabhu Yuvaraj[1], Mirna Garhnayak[2], Shruti Vishal Dev[1], Purna Chandra Mishra[3], Tapan Kumar Patro[4], Loknath Garhnayak[4], Sonali Perti[1] and Nabagata Ganchoudhury[1]

1 Kalinga Institute of Dental Sciences, KIIT Deemed to be University, Bhubaneswar, India

2 Institute of Dental Sciences, SOA University, Bhubaneswar, India

3 School of Mechanical Engineering, KIIT Deemed to be University, Bhubaneswar, India

4 S.C.B. Dental College and Hospital, Cuttack, India

*Address all correspondence to: bapujikar@gmail.com

References

[1] Acharya A, Schroeder D, Schwei K, Chyou P-H. Update on electronic dental record and clinical computing adoption among dental practices in the United States. Clinical Medicine & Research. 2017;**15**(3-4):59-74

[2] Chyou PH, Schroeder D, Schwei K, Acharya A. Statistical application and vcost saving in a dental survey. Clinical Medicine & Research. 2017;**15**:1-5

[3] Vale F, Scherzberg J, Cavaleiro J, Sanz D, Caramelo F, Maló L, et al. 3D virtual planning in orthognathic surgery and CAD/CAM surgical splints generation in one patient with craniofacial microsomia: A case report. Dental Press Journal of Orthodontics. 2016;**21**(1):89-100

[4] Saini R. Information technology in dentistry. Dentistry. 2016;**6**(8):1000e120

[5] Albuha Al Mussawi RM, Farid F. Computer-based technologies in dentistry: Types and applications. Journal of Dentistry of Tehran University of Medical Sciences. 2016;**13**(3):215-222

[6] Luthra RP, Gupta R, Kumar N, Mehta S, Sirohi R. Virtual articulators in prosthetic dentistry: A review. Journal of Advanced Medical and Dental Sciences Research. 2015;**3**(4):117-121

[7] Ponto K, Kohlmann J, Tredinnick R. DSCVR: Designing a commodity hybrid virtual reality system. Virtual Reality. 2015;**19**(1):57-70

[8] Tanja-Dijkstra K, Pahl S, White MP, Andrade J, May J, Stone RJ, et al. Can virtual nature improve patient experiences and memories of dental treatment? A study protocol for a randomized controlled trial. Trials. 2014;**15**:90

[9] Mallikarjun SA, Tiwari S, Sathyanarayana S, Devi PR. Haptics in periodontics. Journal of Indian Society of Periodontology. 2014;**18**(1):112-113

[10] Proffit WR, Fields HW, Sarver DM, Ackerman JL. Contemporary Orthodontics. 5th ed. St. Louis: Elsevier-Mosby; 2013. p. 355

[11] Jevremović DP, Puškar TM, Budak I, Vukelić D, Kojić V, Eggbeer D, et al. An RE/RM approach to the design and manufacture of removable partial dentures with a biocompatibility analysis of the F75 Co-Cr SLM alloy. Materiali in Tehnologije. 2012;**46**(2):123-129

[12] Shahrbanian S, Ma X, Aghaei N, Korner-Bitensky N, Moshiri K, Simmonds MJ. Use of virtual reality (immersive vs.non immersive) for pain management in children and adults: A systematic review of evidence from randomized controlled trials. European Journal of Experimental Biology. 2012;**2**(5):1408-1422

[13] Al Mortadi N, Eggbeer D, Lewis J, Williams RJ. CAD/CAM applications in the manufacture of dental appliances. American Journal of Orthodontics and Dentofacial Orthopedics. 2012;**142**(5):727-733

[14] Gugwad R, Kore A, Basavakumar M, Arvind M, Sudhindra M, Ramesh C. Virtual articulators in prosthodontics. International Journal of Dental Clinics. 2011;**3**(4):39-41

[15] Dutã M, Amariei CI, Bodan CM, Popovici DM, Ionescu N, Nuca CI. An overview of virtual and augmented reality in dental education. Journal of Oral Health and Dental Management. 2011;**10**(1):42-49

[16] Takato T. New technologies in oralscience. Japan Medical Association Journal. 2011;**54**(3):194-196

[17] Rhienmora P, Haddawy P, Khanal P, Suebnukarn S, Dailey MN. A virtual reality simulator for teaching and evaluating dental procedures. Methods of Information in Medicine. 2010;**49**(4):396-405

[18] Sato K, Fukumori S, Matsusaki T, Maruo T, Ishikawa S, Nishie H, et al. Non-immersive virtual reality mirror visual feedback therapy and its application for the treatment of complex regional pain syndrome: An open-label pilot study. Pain Medicine. 2010;**11**(4):622-629

[19] Konukseven EI, Önder ME, Mumcuoglu E, Kisnisci RS. Development of a visio-haptic integrated dental training simulation system. Journal of Dental Education. 2010;**74**(8):880-891

[20] Van Krevelen DW, Poelman R. A survey of augmented reality technologies, applications and limitations. The International Journal of Virtual Reality. 2010;**9**(2):1

[21] Han J, Wang Y, Lü P. A preliminary report of designing removable partial denture frameworks using a specifically developed software package. The International Journal of Prosthodontics. 2010;**23**(4):370-375

[22] SMI B, Jakimowicz JJ. What is going on in augmented reality simulation in laparoscopic surgery? Surgical Endoscopy. 2009;**23**(8):1693-1700

[23] Azari A, Nikzad S. The evolution of rapid prototyping in dentistry: A review. Rapid Prototyping Journal. 2009;**15**(3):216-225

[24] Fuster-Torres MÁ, Albalat-Estela S, Alcañiz-Raya M, Peñarrocha-Diago M. CAD/CAM dental systems in implant dentistry: Update. Medicina Oral Patología Oral y Cirugía Bucal. 2009;**14**(3):E141-E145

[25] Beuer F, Schweiger J, Edelhoff D. Digital dentistry: An overview of recent developments for CAD/CAM generated restorations. British Dental Journal. 2008;**204**(9):505-511

[26] Daniel JP. CAD/CAM today: A 22-year retrospective. Inside Dentistry. 2008;**4**(10):12

[27] Bibb RJ, Eggbeer D, Williams RJ, Woodward A. Trial fitting of a removable partial denture framework made using computer-aided design and rapid prototyping techniques. Proceedings of the Institution of Mechanical Engineers. Part H. 2006;**220**(7):793-797

[28] Bimber O, Raskar R. SpatialAugmented Reality: Merging Real and Virtual Worlds. Wellesley, Massachusetts, USA: AK Peters. Ltd; 2005

[29] Liu PR. A panorama of dental CAD/CAM restorative system. The Compendium of Continuing Education in Dentistry. 2005;**26**(7):507-512

[30] Mujber TS, Szecsi T, MSJ H. Virtual reality applications in manufacturing process simulation. Journal of Materials Processing Technology. 2004;**155**(156):1834-1838

[31] Shuhaiber JH. Augmented reality in surgery. Archives of Surgery. 2004;**139**(2):170-174

[32] LeBlanc VR, Urbankova A, Hadavi F, Lichtenthal RM. A preliminary study in using virtual reality to train dental students. Journal of Dental Education. 2004;**68**(3):378-383

[33] Buchanan JA. Experience with virtual reality-based technology in teaching restorative dental procedures. Journal of Dental Education. 2004;**68**(12):1258-1265

[34] Aggarwal R, Moorthy K, Darzi A. Laparoscopic skills training

and assessment. The British Journal of Surgery. 2004;**91**(12):1549-1558

[35] Raigrodski AJ. Contemporary materials and technologies for all ceramic fixed partial dentures: A review of the literature. The Journal of Prosthetic Dentistry. 2004;**92**(6):557-562

[36] Ausburn LJ, Ausburn FB. Desktop virtual reality: A powerful new technology for teaching and research in industrial teacher education. Journal of Industrial Teacher Education. 2004;**41**(4):1-16

[37] Hughes CW, Page K, Bibb R, Taylor J, Revington P. The custom made titanium orbital floor prosthesis in reconstruction for orbital floor fractures. The British Journal of Oral & Maxillofacial Surgery. 2003;**41**(1):50-53

[38] McCloy R, Stone R. Virtual reality in surgery. BMJ. 2001;**323**(7318):912-915

[39] Schultheis MT, Rizzo AA. The application of virtual reality technology in rehabilitation. Rehabilitation Psychology. 2001;**46**(3):296-311

[40] Ryan ML. Immersion vs. interactivity: Virtual reality and literary theory. SubStance. 1999;**28**(2):110-137

[41] Connacher HI, Jayaram S, Lyons KW. Virtual assembly using virtual reality techniques. Computer-Aided Design. 1997;**29**(8):575-584

[42] Steuer J. Defining virtual reality: Dimensions determining telepresence. The Journal of Communication. 1992;**42**(4):73-93

Edited by Monika Elzbieta Machoy

The currently available technical and technological solutions of visualization in dentistry are a number of possibilities in creating images useful both for dentists and technicians. To gain a three-dimensional image of a patient's face and profile to visualize changes in appearance after applying a specific therapeutic method in the field of prosthodontics or orthodontics is no longer a problem. The same applies to a very accurate scan of the area to be treated - the exact map of the working field, on the basis of which the implementation of even very difficult dental procedures can be easily planned. Equally available are three-dimensional images of the patient's skull. The book presents the newest means and capabilities of visualization in different fields of dentistry.

ISSN 2631-5343
ISBN 978-1-83962-188-8
9 781839 621888

Published in London, UK

IntechOpen