Editors: D. Wismeijer, S. Barter, N. Donos

ITI International Team for Implantology

ITI Treatment Guide

Volume 11

Digital Workflows in Implant Dentistry

Authors:
G. Gallucci
C. Evans
A. Tahmaseb

ENGLISH | Deutsch | Français | Italiano | Español | Português | Türkçe | Русский | 日本語 | 中文

QUINTESSENCE PUBLISHING

ITI Treatment Guide
Volume 11

ITI Treatment Guide

Editors:
D. Wismeijer, S. Barter, N. Donos

ITI International Team for Implantology

Authors:
G. Gallucci, C. Evans, A. Tahmaseb

Volume 11

Digital Workflows in Implant Dentistry

QUINTESSENCE PUBLISHING

Berlin, Barcelona, Chicago, Istanbul, London, Mexico City,
Milan, Moscow, Paris, Prague, Seoul, Tokyo, Warsaw

German National Library CIP Data

The German National Library has listed this publication in the German National Bibliography. Detailed bibliographical data are available at http://dnb.ddb.de.

QUINTESSENCE PUBLISHING

© 2019 Quintessenz Verlags-GmbH
Ifenpfad 2 – 4, 12107 Berlin, Germany
www.quintessenz.de

Illustrations:	Ute Drewes, Basel (CH), www.drewes.ch
Copyediting:	Triacom Dental, Barendorf (DE), www.triacom.com
Graphic concept:	Wirz Corporate AG, Zürich (CH)
Production:	Juliane Richter, Berlin (DE)
Printing:	Aumüller Druck GmbH & Co. KG, Regensburg (DE), www.aumueller-druck.de

Printed in Germany
ISBN: 978-3-86867-385-2

The materials offered in the ITI Treatment Guide are for educational purposes only and intended as a step-by-step guide to the treatment of a particular case and patient situation. These recommendations are based on the conclusions of the ITI Consensus Conferences and, as such, are in line with the ITI treatment philosophy. These recommendations, nevertheless, represent the opinions of the authors. Neither the ITI nor the authors, editors, or publishers make any representation or warranty for the completeness or accuracy of the published materials and as a consequence do not accept any liability for damages (including, without limitation, direct, indirect, special, consequential, or incidental damages or loss of profits) caused by the use of the information contained in the ITI Treatment Guide. The information contained in the ITI Treatment Guide cannot replace an individual assessment by a clinician and its use for the treatment of patients is therefore the sole responsibility of the clinician.

The inclusion of or reference to a particular product, method, technique or material relating to such products, methods, or techniques in the ITI Treatment Guide does not represent a recommendation or an endorsement of the values, features, or claims made by its respective manufacturers.

Some of the manufacturer and product names referred to in this publication may be registered trademarks or proprietary names, even though specific reference to this fact is not made. Therefore, the appearance of a name without designation as proprietary is not to be construed as a representation by the publisher that it is in the public domain.

The tooth identification system used in this ITI Treatment Guide is that of the FDI World Dental Federation.

The ITI Mission is …

"… to serve the dental profession
by providing a growing global
network for life-long learning
in implant dentistry through
comprehensive quality education
and innovative research to the benefit
of the patient."

Preface

Since the first Treatment Guide appeared in 2007, the field of implant dentistry has progressed significantly in terms of implant design, surgical techniques, and materials, as well as abutment design and restorative materials. In recent years, however, one of the changes that is having far-reaching effects on how we practice implant dentistry has been the introduction of digital workflows—with the associated benefits as well as the challenges they pose to practitioners.

At the 6th ITI Consensus Conference in Amsterdam in 2018, progress in digital technology was examined by one of the working groups that looked into, in particular, computer-aided implant surgery, implant impression techniques, the accuracy of linear measurement of cone-beam CT images, and the accuracy of static computer-aided implant surgery.

The fruits of these discussions have been integrated in this volume. In 14 chapters that include 13 clinical cases, the authors have covered a broad spectrum of technologies, procedures, and approaches, as well as offering recommendations and taking a look at developments currently in the pipeline.

S. Barter N. Donos D. Wismeijer

Acknowledgments

The authors would like to express their gratitude to Dr. Friedrich Buck for his excellent support in the preparation and coordination of this Treatment Guide. We would also like to thank Ms. Ute Drewes for the professional illustrations, Ms. Juliane Richter (Quintessence Publishing) for the typesetting and for coordinating the production workflow, Mr. Per N. Döhler for the language editing, as well as Mr. Stephen Barter for additional editorial assistance.

Editors and Authors

Editors:

Daniel Wismeijer
DMD, Professor
Head of the Department of Oral Implantology and Prosthetic Dentistry
Section of Implantology and Prosthetic Dentistry
Academic Center for Dentistry Amsterdam (ACTA)
Free University
Gustav Mahlerlaan 3004
1081 LA Amsterdam
Netherlands
Email: d.wismeijer@acta.nl

Stephen Barter
BDS, MSurgDent RCS
Specialist in Oral Surgery
Hon Senior Clinical Lecturer/Consultant Oral Surgeon
Centre for Oral Clinical Research
Institute of Dentistry
Barts and The London School of Medicine and Dentistry, Queen Mary University of London (QMUL)
Turner Street
London E1 2AD
United Kingdom
Email: s.barter@gmx.com

Nikolaos Donos
DDS, MS, FHEA, FDSRC, PhD
Professor, Head and Chair, Periodontology and Implant Dentistry,
Head of Clinical Research
Institute of Dentistry, Queen Mary University of London,
Institute of Dentistry, Barts and The London School of Medicine and Dentistry
Turner Street
London E1 2AD
United Kingdom
Email: n.donos@qmul.ac.uk

Authors:

German O. Gallucci
DDS, Dr med dent (DMSc), PhD
Raymond J. and Elva Pomfret Nagle Associate Professor of Restorative Dentistry
Chair, Department of Restorative Sciences and Biomaterial Sciences
Harvard School of Dental Medicine
188 Longwood Avenue
Boston, MA 02115
USA
Email: german_gallucci@hsdm.harvard.edu

Christopher Evans
BDSc Hons (Qld), MDSc (Melb); MRACDS (Pros), FPFA
Suite 4, 1st Floor, 232 Bay St
Brighton, VIC 3186
Australia
Email: chris@evansprosthodontics.com

Ali Tahmaseb
DDS, PhD
Associate Professor
Academic Centre for Dentistry Amsterdam (ACTA)
Field of Oral Implantology and Prosthodontics
Gustav Mahlerlaan 3004
1081 LA Amsterdam
Netherlands
-and-
Associate Professor
Department of Oral and Maxillofacial Surgery
Erasmus MC
P.O. Box 2040
3000 CA Rotterdam
Netherlands
Email: ali@tahmaseb.eu

Contributors

Nawal Alharbi
BDS, MSc, PhD
Department of Prosthetic Dental Science
King Saud University
Riyadh 4545, Saudi Arabia
Email: nalharbi@ksu.edu.sa

Orlando Álvarez del Canto
DDS, MS
Oral Implantology
Av. Presidente Kennedy 7100 Of. 601
Vitacura, Santiago, 7650618, Chile
Email: dr.alvarez@oseointegracion.cl

Jyme Charette
DMD, MSD
Renew Institute: Beyond Dentistry
4938 Brownsboro Road, Suite 205
Louisville, KY 40222, USA
Email: jyme@renew-institute.com

Krzysztof Chmielewski
MSc
SmileClinic
Karola Szymanowskiego 2
80-280 Gdańsk, Poland
Email: krischmielewski@me.com

André Barbisan de Souza
DDS, MSc
Department of Prosthodontics
Tufts University School of Dental Medicine (TUSDM)
One Kneeland Street, DHS-1242
Boston, MA 02111, USA
Email: andre.de_souza@tufts.edu

Wiebe Derksen
DDS, MSc
Academic Centre for Dentistry Amsterdam (ACTA)
Oral Implantology and Restorative Dentistry
Gustav Mahlerlaan 3004
1081 LA Amsterdam, Netherlands
Email: w.derksen@acta.nl

Simon Doliveux
DDS, MMSc
Department of Restorative Dentistry and
Biomaterial Sciences
Harvard School of Dental Medicine
188 Longwood Avenue
Boston, MA 02130, USA
Email: simon_doliveux@hsdm.harvard.edu

Christianne Fijnheer
MSc, MSc
Academic Centre for Dentistry Amsterdam (ACTA)
Oral Implantology and Restorative Dentistry
Gustav Mahlerlaan 3004
1081 LA Amsterdam, Netherlands
Email: christianne.fijnheer@dentalclinics.nl

Gary Finelle
DDS
Dental7paris
59 Avenue de la Bourdonnais
75007 Paris, France
Email: gary.finelle@dental7paris.com

Adam Hamilton
BDSc, FRACDS, DCD
Harvard School of Dental Medicine
Restorative Dentistry and Biomaterials Sciences
Division of Regenerative and Implant Sciences
188 Longwood Avenue
Boston, MA 02115, USA
Email: adam_hamilton@hsdm.harvard.edu

Bassam Hassan
DDS, MSc, PhD
Prosthodontist
Acibadem International Medical Centre
Arlandaweg 10
1043 HP Amsterdam, Netherlands
Email: nassam.hassan@acibademimc.com

Tim Joda
Prof Dr med dent, DMD, MSc, PhD
University of Basel
Reconstructive Dentistry
University Center for Dental Medicine Basel (UZB)
Hebelstrasse 3
4056 Basel, Switzerland
Email: tim.joda@unibas.ch

Ali Murat Kökat
DDS, PhD
Prosthodontist
Professor, Istanbul Okan University
Faculty of Dentistry
Akfirat
Istanbul 34359, Turkey
Email: alimurat@outlook.com

Alejandro Lanis
DDS, MS
Oral Implantology
Assistant Professor, School of Dentistry
Pontificia Universidad Católica de Chile
Private Practice
Av. Presidente Kennedy 7100 Of. 601, Vitacura
Santiago, 7650618, Chile
Email: dr.alejandrolanis@gmail.com

Wei-Shao Lin
DDS, FACP
Diplomate of the American Board of Prosthodontics
Associate Professor, Indiana University School of Dentistry, Department of Prosthodontics
1121 W Michigan Street, DS-S406
Indianapolis, IN 46202, USA
Email: weislin@iu.edu

Dean Morton
BDS, MS, FACP
Indiana Dental Association Professor and Chair
Department of Prosthodontics
Director, Center for Implant, Esthetic and Innovative Dentistry
Indiana University School of Dentistry
1121 W. Michigan Street, DS-S316
Indianapolis, IN 46202, USA
Email: deamorto@iu.edu

Panos Papaspyridakos
DDS, MS, PhD
Tufts University School of Dental Medicine
Division of Postgraduate Prosthodontics
1 Kneeland Street
Boston, MA 02111, USA
Email: panpapaspyridakos@gmail.com

Waldemar D. Polido
DDS, MS, PhD
Clinical Professor and Program Director, Predoctoral Oral and Maxillofacial Surgery
Co-Director, Center for Implant, Esthetic and Innovative Dentistry, Indiana University School of Dentistry
1050 Wishard Boulevard, Room 2200
Indianapolis, IN 46202, USA
Email: wdpolido@iu.edu

Gerry Raghoebar
DDS, MD, PhD
Professor
University Medical Center Groningen
Hanzeplein 1
9700 RB Groningen, Netherlands
Email: g.m.raghoebar@umcg.nl

R. H. Schepers
DDS, MD, PhD
Assistant Professor
University Medical Center Groningen
Hanzeplein 1
9700 RB Groningen, Netherlands
Email: r.h.schepers@umcg.nl

Newton Sesma
DDS, MSD, PhD
University of São Paulo School of Dentistry
Av. Prof. Lineu Prestes, 2227
São Paulo – SP, 05508-000, Brazil
Email: sesma@usp.br

Arjan Vissink
DDS, MD, PhD
Professor
University Medical Center Groningen
Hanzeplein 1
9700 RB Groningen, Netherlands
Email: a.vissink@umcg.nl

M. J. H. Witjes
DDS, MD, PhD
Associate Professor
University Medical Center Groningen
Hanzeplein 1
9700 RB Groningen, Netherlands
Email: m.j.h.witjes@umcg.nl

Table of Contents

1 Introduction

G. Gallucci

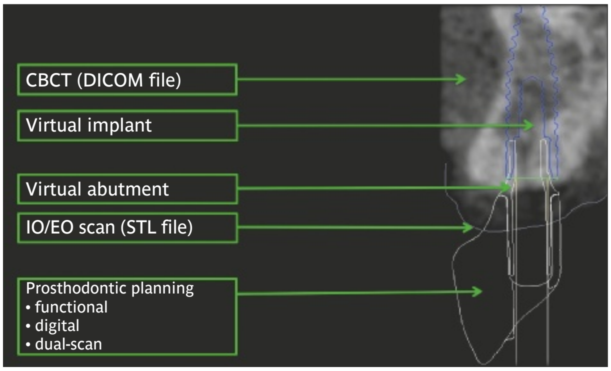

Fig 1 Digital dataset used for planning in implant prosthodontics. CBCT: Cone-beam computed tomography. DICOM: Digital imaging and communications in medicine. IOS: Intraoral scanner. EOS: Extraoral scanner. STL: Standard tessellation language (formerly stereolithography).

The present Volume 11 of the ITI Treatment Guide explores the advances in implant dentistry made by incorporating digital dental technology (DDT). In this context, current implant prosthodontic protocols are revisited to accommodate modern technology and techniques.

This volume begins by addressing the technology and the necessary tools for the incorporation of DDT in a digital workflow, along with the clinical steps required for data acquisition. This includes imaging by cone-beam computed tomography (CBCT), intraoral scanning (IOS), extraoral scanning (EOS), and facial scanning (FS). It then turns to the different software tools needed to manipulate the digital data. A section is also dedicated to the integration of DDT into patient care by merging different datasets to virtually reconstruct the patient's orofacial anatomy.

An example dataset used in DDT for virtual implant planning incorporates several digital elements, as shown in Fig 1. Two main aspects of this dataset are the technology used for capturing orofacial structures in digital format and the software used to manipulate those digital files in order to perform virtual treatment planning, or to use computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology.

1.1 Acquiring Digital Data

Different technologies are used to capture orofacial structures in a digital format. For instance, a CBCT unit is used to obtain a digital 3D rendering of the selected anatomical areas.

Chapter 2 describes in detail the imaging techniques and specifications for CBCT use in Implant Dentistry. While CBCT has the capability to capture most orofacial structures, it is mostly used to digitally replicate structures of higher density such as bone and teeth. A CBCT will produce a file in a format called DICOM (*Digital Imaging and Communications in Medicine*); this is a standard format commonly accepted in medicine.

CBCT images are often merged with IOS or EOS images obtained with a surface scanner. These types of scanners generally yield the generic STL file format (formerly known as *Stereolithography* format, now *Standard Tessellation Language* format). STL files are native to the stereolithography CAD software used by 3D systems. Unlike DICOM files, surface scanners produce a 3D representation of the surface of a scanned object. For this reason, a more detailed 3D representation of the scanned anatomical structures can be obtained when STL files are matched with a DICOM file.

Chapter 3 describes digital intraoral and extraoral scanning techniques as well as the associated technology. In addition to intraoral and extraoral scanning, the tissues of the face can be captured by a facial scanner (FS) to produce an additional dataset that can be merged with DICOM and IOS/EOS STL files, the goal being to obtain a complete virtual representation of the patient.

The current state of face scanning and an overview of the currently available technology are presented in ***Chapter 4***.

1.2 Manipulating Digital Data

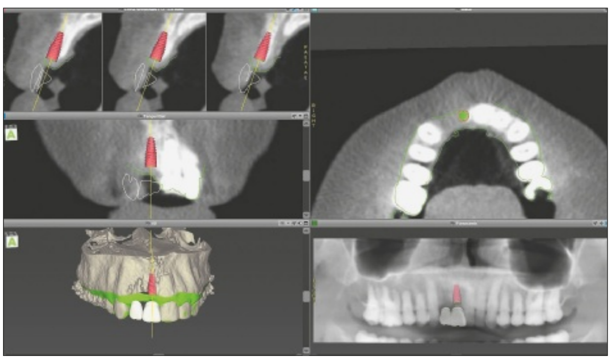

Fig 2 Virtual planning software for implant prosthodontics. Grey: DICOM. Green: STL. Red: Proposed implant. White: digital prosthetic setup. – Top left window: Cross-sectional views. Top right window: Axial view. Middle left window: Tangential view. Bottom left window: 3D reconstruction. Bottom right window: Panoramic view.

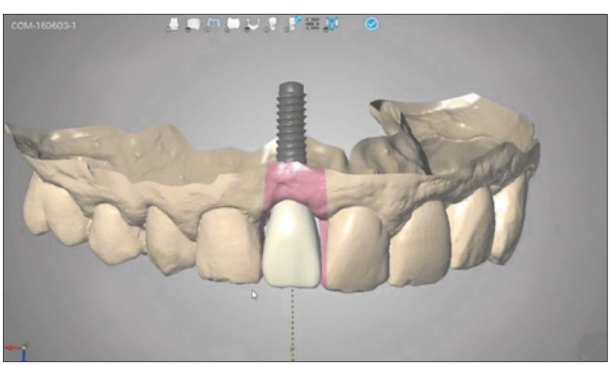

Fig 3 Screenshot of a CAD screen for an implant crown. (Courtesy of Chris Evans.)

Different software packages are available that can process digital files such as DICOM and STL for the virtual planning of implant placement, the digital design of surgical guides, or the digital fabrication of implant-supported prostheses. These software packages are divided into two main groups: (1) virtual implant-planning software and (2) CAD/CAM software. These two digital platforms can also be integrated to facilitate the free exchange of information.

Virtual planning software is used to select the ideal implant type and plan the implant's position in relation to the anatomy of the patient and the desired implant-prosthetic design. Fig 2 shows an example display of virtual planning software that has been used to plan an implant case.

Several planning steps are performed in this platform as follows:

1. Importing, segmenting, and aligning DICOM files
2. Setting the panoramic curve
3. Matching of DICOM and STL files
4. Digital tooth set-up (prosthetic planning)
5. Virtual implant selection and planning
6. Virtual abutment selection and planning
7. Virtual bone augmentation planning
8. Digital design of a surgical template for guided implant placement
9. Rendering a surgical protocol
10. Connectivity with CAD/CAM software

These steps are described in detail in ***Chapters 5 to 9***.

In dentistry, CAD/CAM software is generally used for digital prosthodontics. Here, the main file format used is an STL file obtained via an IOS or EOS unit. Initially, the CAD side of the software is used to manipulate the STL file to design diagnostic models, implant abutments, a temporary implant prosthesis, and the final implant-supported prosthesis (Fig 3).

For implant-supported prostheses, the implant position is captured by an IOS or EOS image of a master cast using scanbodies (impression copings for digital surface scanning). These are geometric objects of known dimension (Fig 4) connected to the dental implant instead of the regular impression coping. The scanbody is usually constructed from PEEK material and has a dimension that can be recognized by the CAD software. Based on the scanbodies, the CAD software recognizes the implant type and spatial orientation allowing for the subsequent design of the implant prosthesis. CAD software packages offer an array of tools and commands for the virtual design of implant prostheses.

Fig 4 Scanbody in situ.

Once the CAD process is completed, a new STL file can be exported to various types of hardware to perform the CAM portion of the process. Implant-supported restorations can be manufactured by two main processes: additive or subtractive manufacturing. These steps are described in detail in ***Chapters 10 and 11***.

Additive manufacturing (AM) is the process of joining materials to make objects from 3D model data, usually layer upon layer. Examples of additive 3D printing/manufacturing are:

1. Vat photopolymerization (digital light processing)
2. Powder-bed fusion (laser sintering)
3. Binder jetting (powder-bed and inkjet 3D printer)
4. Material jetting (multi-jet modeling)
5. Sheet lamination (selective deposition lamination)
6. Material extrusion (fused filament fabrication)
7. Directed energy deposition (laser metal deposition)

Subtractive manufacturing is a process by which 3D objects are constructed by successively cutting material away from a solid block of material, also known as milling or machining.

The clinical implementation of DDT in implant dentistry should optimize patient care by simplifying treatment while maintaining or improving the predictability of the outcome. Through a series of step by step clinical cases presented in ***Chapter 13***, the reader will be able to consider the integration of digital protocols into their practice by understanding the technology necessary for acquiring and processing digital information and for the implementation of appropriate treatment protocols.

The progression of chapters in this volume of the ITI Treatment Guide was carefully conceived in a logical sequence to illustrate a clinical workflow. This workflow, when applied to DDT, is of paramount significance, since it will influence the treatment sequence. ***Chapter 7*** addresses digital workflows applied to patient care to integrate technology, techniques, and treatment sequencing with DDT to enhance patient safety and treatment reproducibility.

The authors offer clinical recommendations, assess future developments, and discuss the learning curve associated with the adoption of emerging technologies, with the associated risks and benefits. DDT is a very rapidly changing field—a field producing changes faster than the profession can absorb into clinical practice. The speed of progress is certainly fast enough to render any attempt at printed scientific literature unlikely to remain current for very long!

2 Surface Scans

C. Evans

2.1 Introduction

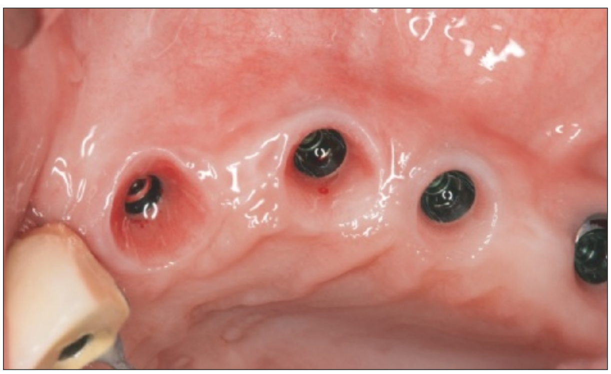

Fig 1 The mobility of the peri-implant tissues, vestibular mucosa, and frenal attachments may complicate the exact duplication of implants and related structures.

When undertaking dental implant procedures, an accurate duplication of the teeth/implants and surrounding tissues is required for both treatment planning and to enable fabrication of the prosthesis. Historically, such duplicates have taken the form of a physical stone model or working cast, which is produced from an impression of the oral cavity. Exact duplication of the structures in the oral cavity is complicated by factors such as multiple undercut surfaces due to variations in tooth morphology and axial inclination, the presence of fixed and movable soft tissues, frenal attachments, and the underlying muscles (Fig 1). The mouth is also an inherently moist environment due to the presence of saliva and crevicular fluid, which can compromise the accurate capture of shapes and contours without distortion. Inaccuracies can also arise from different properties of impression materials and issues relating to tray construction and rigidity, or patient compliance and movements.

Conventional impression materials are often hydrophilic to accommodate moisture and elastomeric to allow reversible deformation on removal from the mouth. The desired extent of the surface to be captured is determined by the type of prosthesis planned. For removable prostheses, a full-border extension of the impression will be necessary to avoid overextension of the prosthesis into the moveable tissues.

Impressions are then poured in type 3 or type 4 dental stone to provide a physical model. Inaccuracies can also occur in model production. When prosthetic reconstructions are made on immobile structures such as dental implants, inaccuracies in the dental cast as a consequence of the above-mentioned factors can result in an incorrect fit of the prosthetic framework. This in turn will result in delays, additional costs, frustration for the dentist, and patient dissatisfaction.

The introduction of the computer-aided design/computer-aided manufacture (CAD/CAM) concept to replace conventional impression/model techniques was first presented by François Duret in his thesis presented at the Université Claude Bernard, Faculté d'Odontologie, in Lyon, France in 1973, entitled "Empreinte Optique" (Optical Impression). Duret was able to complete intraoral scans using two cameras, two lasers, and a fiber-optic feed to enable the information to be transmitted to a large dental laboratory who could then manufacture a CAD/CAM restoration. This technology was subsequently refined by Werner Mörmann and Marco Brandestini in the 1980s at the University of Zürich for use in restorative dentistry and became commercially available as a CAD/CAM system for dental restorations in 1987 (Cerec; Dentsply Sirona, Bensheim, Germany). This was the first optical non-contact direct intraoral scanning system.

With the introduction of CAD/CAM in dental prosthetics, the first step in the workflow is acquiring a digital representation of the oral cavity. Digitization of the important structures by means of surface scans is considered a more straightforward technique than conventional impressions and may show less variability (Figs 2 and 3).

Fig 2 Clinical case with advanced gingival recession.

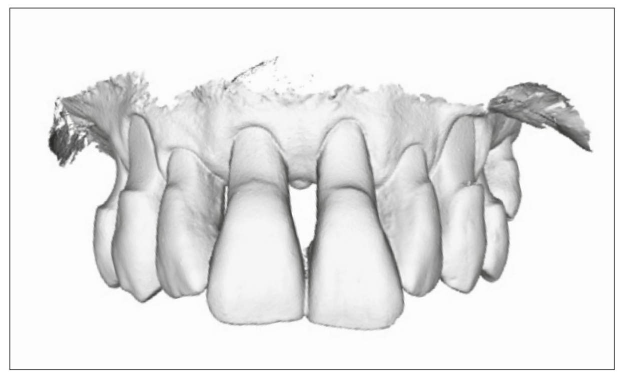

Fig 3 Surface scan of the clinical case in Fig 2.

2.2 Analog Impressions

Conventional impressions have been used for many years to capture the position of dental implants. They require an impression post to be placed onto the dental implant and a viscous impression material to set in the patient's mouth. A very high degree of dimensional accuracy is required for these materials to accurately duplicate the positions of the implants (Fig 4), and such materials have not been without limitations (Hamalian and coworkers 2011).

2.2.1 Material Accuracy

Traditionally, different types of impression material may be selected depending on the required level of accuracy for the intended dental procedure (Hamalian and coworkers 2011). The accuracy of impression materials may be affected by:

- Storage conditions
- Temperature
- Errors in mixing dosage and time
- Tray rigidity and positioning in the mouth
- Clinical technique
- Patient movement
- Setting time
- Continued chemical reaction after initial setting

Accurate surface detail is essential to avoid occlusal inaccuracies when positioning the antagonist model. Injectable low-viscosity materials are first flowed over surfaces to reduce the risk of air voids, and a heavier viscosity material is then placed in an impression tray, which supports and slightly displaces the material completely around the target structure. The time for setting will vary depending on the nature of the material. Voids or air bubbles within the impression may further reduce the accuracy of the impression.

2.2.2 Patient Comfort

Impression materials frequently require setting times in excess of four minutes. While many patients can tolerate conventional impression techniques, some patients find the procedure unpleasant, reporting a gagging feeling, excess saliva production, TMJ pain from prolonged opening, restricted access for appropriately fitting trays sizes, breathing difficulties, or an unpleasant taste.

Fig 4 Conventional impression material being flowed around impression posts.

Fig 5 Impression.

2.2.3 Cast Production

When removed from the mouth, the impression material produces a "negative" of the relevant anatomy and requires a suitable dental stone to be poured in order to form a replica of the oral structures. Following removal from the patients' mouth, an appropriately matched laboratory analog is connected to the impression coping within the dental impression (Fig 5). Usually, a removable silicone material will first be placed around the implant analog to replicate the peri-implant soft tissue, and the gypsum stone is subsequently poured (Figs 6 and 7). There is a delay involved in releasing the model, as dental stone requires time for setting. The model itself is prone to dimensional errors caused by factors including:

- The mixing ratio of the dental stone
- Handling by the dental technician
- Surface abrasion and damage such as chipping and cracking
- Additionally, bubble formation can result in poor contact-point accuracy and occlusal errors (Fig 8)

(Buzayan and coworkers 2013; Holst and coworkers 2007).

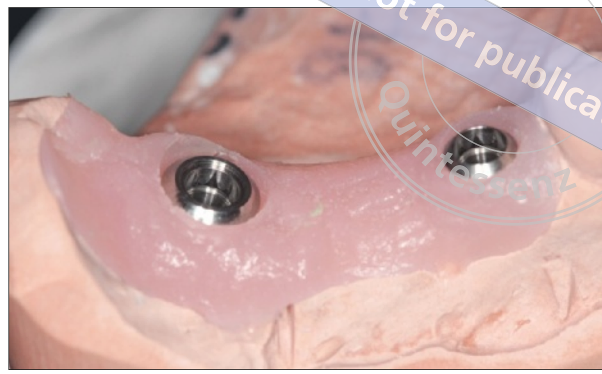

Fig 6 Stone cast with implant analogs in position, gingival mask in place.

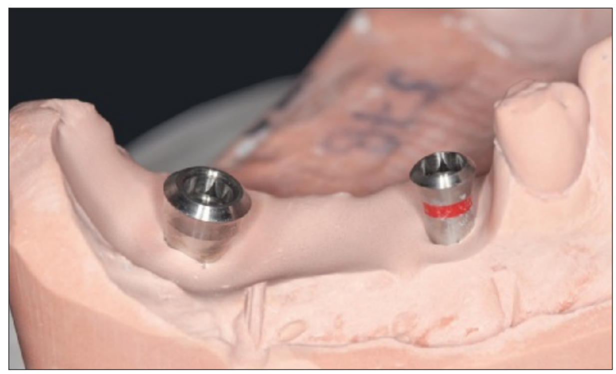

Fig 7 Stone cast with implant analogs in position, gingival mask removed.

Fig 8 Stone cast showing bubbles and dragging, abrasion of the contact points, and residual plaster from articulation, all of which degrade the quality of the model.

2.3 Digital "Impressions"—Digitization of the Oral Cavity

Conventional impression techniques capture the impression coping connected to the dental implant. The production of a CAD/CAM dental prosthesis first requires the digitization of the relevant intraoral structures. A digital or "virtual" working model can then be used for the computer-aided processes.

When scanning dental implants, a geometric object of known dimensions called a scanbody (Fig 10) is connected to the dental implant instead of the conventional impression coping. The scanbody is usually constructed from PEEK material and has dimensions that can be recognized by the CAD software. A surface scan of the clinical situation is then obtained with specialized hardware, producing a digital file that can be imported into software packages for CAD/CAM.

2.3.1 File Formats

The standard file format of intraoral scanners is the STL file (Surface Tessellated Language). This file describes the surface geometry of three-dimensional objects by triangulation in binary code. The STL file format was created in 1987 by 3D Systems (Rock Hill, SC, USA) when they first developed the process of stereolithography (Wong and Hernandez 2012; Joda and coworkers 2017).

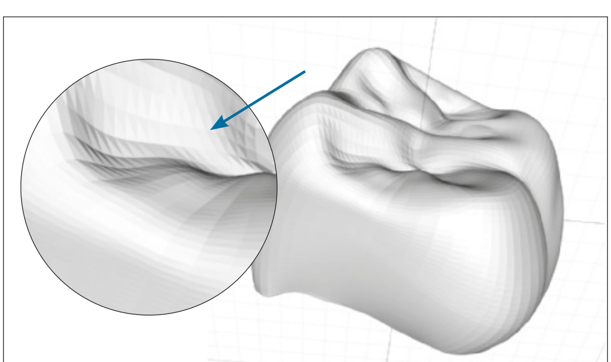

Fig 9 Following translation of the XYZ cloud points to a mesh of 3D triangles, the final contour is represented. Note the discrete appearance of meshed triangular geometry.

Digitization of the oral cavity creates a "point cloud." This is a set of data points in a three-dimensional coordinate system, usually X- Y-, and Z-coordinates, intended to represent the external surface of an object. Point clouds are usually polygon or triangle mesh models converted through a process commonly referred to as surface reconstruction to form the STL file (Fig 9).

The STL file creation links the continuous geometry of small triangles together to form the intended shape. This process can be inaccurate if the size of the mesh triangles is too large to fit the contour of the desired shape; in this case, information will be lost. Smaller triangles achieve a more realistic rendering of the object. Since the geometrical shape of a triangle has sharp edges, additional edges are sometimes added to the overall contour, which will then need to be adjusted to fit the final shape. This process can also introduce inaccuracy to the file, because an algorithm replaces the continuous contour, producing discrete steps in the surface contour.

Other files types also exist to store the data from a digital scan; some are manufacturers' proprietary systems that can only be used with the corresponding software ("closed systems"), while others may be used with multiple software packages ("open systems"). Examples include:

.PLY	Polygon File Format (also known as the Stanford Triangle Format) (Carestream; Rochester, NY, USA)
.OBJ	A simple data format used by the True Definition scanner (3M Espe; St. Paul, MN, USA); the file format is open and has been adopted by many 3D graphics applications
.DCM/.3OXZ	Both open and closed versions exist (3shape; Copenhagen, Denmark)
.RST/.DXD	(Cerec; Dentsply Sirona, Bensheim, Germany)

Reported advantages of these alternative file types over the STL file format include the storage of additional information such as color, texture, and marginal line data. While many different manufacturers employ different file systems, an open system is usually preferred to a closed system: the open system allows the surface scan file type to be used in any CAD software program without the need for file conversion, which is often limited and restricted by licensing arrangements associated with closed systems. There is also the risk of data loss or possible data-set corruption associated with file conversion packages.

The digitization of a complex intraoral morphology can be achieved via three distinct processes:

- Extraoral scanners that scan and digitize a traditional stone model produced using conventional impression techniques
- Extraoral scanners that scan and digitize a conventional impression
- Intraoral scanners, which perform non-contact optical scanning with a light emitting device to directly digitize the oral structures

2.3.2 Extraoral Scanning Systems

Following the production of the traditional gypsum stone cast with embedded analog implant replicas and removable-tissue silicone in place, a dental technician scans the model using a desktop laboratory scanner. Early-generation scanners required a contact probe to trace the contour of the stone model and develop the digital file. This has largely been replaced with non-contact optical scanners, which removes the limitation of the probe being unable to contact certain areas due to its physical size. A laboratory scanner uses a model holder that moves the cast in the path of a light-emitting device. Early-generation scanners required the model to be placed within a zone of scanning accuracy on a plasticine supporting base, but most scanners now utilize rotating model supports to enable complete visualization of surfaces and their associated undercuts.

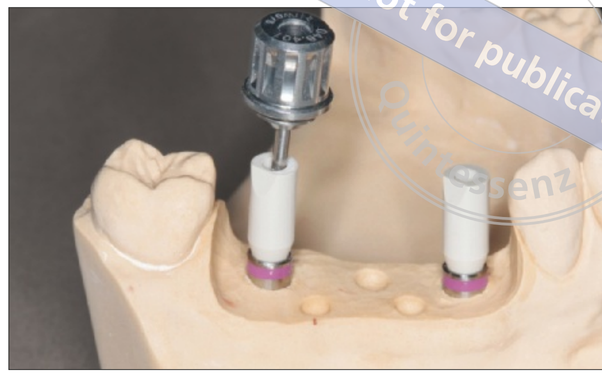

Fig 10 Scanbody connection.

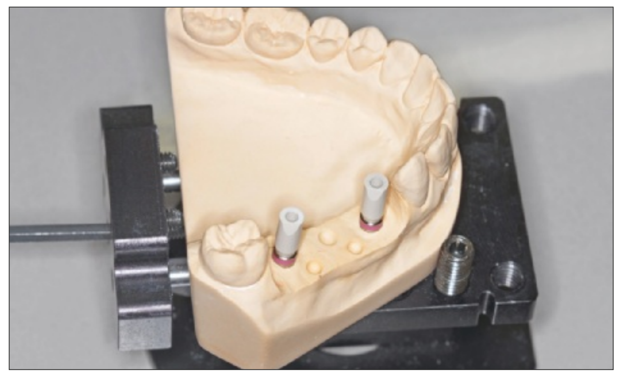

Fig 11 Model holder.

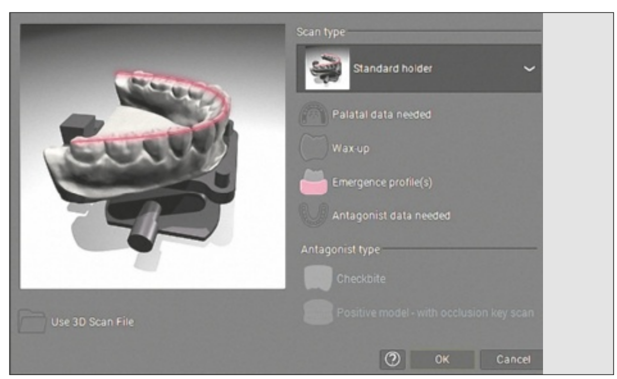

Fig 12 Setup for the laboratory scan.

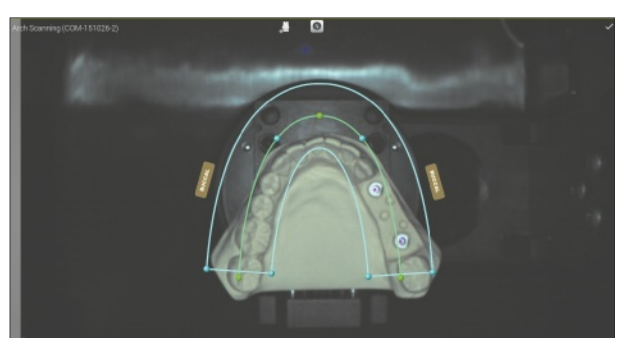

Fig 13 Preview to orient position of cast.

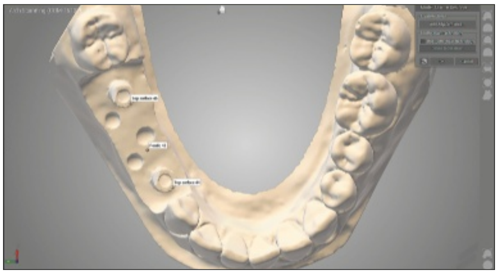

Fig 14 Implant scanbody located.

Fig 15 Virtual model ready for the CAD process.

Since the model is passed into a static light-emitting/light-receiving device, the rendering of the image is completed in a single plane. This offers the advantage of greater interpositional accuracy of the components within the model. Laboratory scanners are preferred when digitizing working casts for fabricating large frameworks used in full-arch reconstructions. The scanbodies must be placed in the cast with care to avoid damage to their fitting surfaces. The scanner software employs a strategy where the first scan pass is of the scanbodies without the removable soft tissue in place. The scanbodies are subsequently removed, and the removable silicone tissue is replaced on the cast; a second "tissue" scan is then performed. The laboratory software will remove any matched duplicate surfaces and insert a "virtual" implant into the rendered image of the cast so that a digital replica of the oral situation is created, with a removable tissue layer (Figs 10 to 15).

2.3.3 Impression Scanning

An alternative to scanning the object directly is to scan a conventional negative impression. This technique is essentially only useful for non-implant restorative cases. The impression is placed in a holder and inserted into the laboratory scanner. The impression material selected must contain a filler particle, usually titanium dioxide, to make it readable by the scanner. Limitations of the technique are found, for example in cases with long clinical crowns, perhaps due to natural teeth with periodontal attachment loss, as the full depth of contour can be obscured from the scanner head.

2.3.4 Intraoral Scanning Systems

Optical, non-contact, direct intraoral scanning systems use a "wand" containing a light-emitting device and integrated sensors to capture the intraoral form directly within the patient's mouth, generating a digital replica of the dentition and related structures. Direct digitization offers clinicians the benefit of being able to view the digital replica of the oral cavity without delay.

Examples of technologies available for intraoral scanning include:

- Active Wavefront Sampling (3M True Definition scanner; 3M Espe, St. Paul, MN, USA)
- Confocal imaging (iTero, Amsterdam, Netherlands)
- Triangulation stripe light projection (Cerec; Dentsply Sirona, Bensheim, Germany)
- Optical coherence tomography (E4D, Richardson, TX, USA)

Again, for intraoral scanning of dental implants, a scanbody is inserted into the implant (Fig 16).

The intraoral form presents a challenge to optical scanning in that the surfaces to be captured as an image are highly reflective or have a high degree of translucency. Depending on the optical scanning technique employed, powder-coating with a titanium or magnesium dioxide powder may be required to enable the scanner to capture the image (Fig 17). Some scanners do not require the application of powder to capture the scanbody's position accurately.

Fig 16 Scanbody in situ.

Fig 17 Scanbody following light scan-powder application.

Fig 18 Retraction of the patient's lips helps provide access for the scanning device. In this case, an Optragate (Ivoclar Vivadent, Schaan, Liechtenstein) was used to maintain lip retraction.

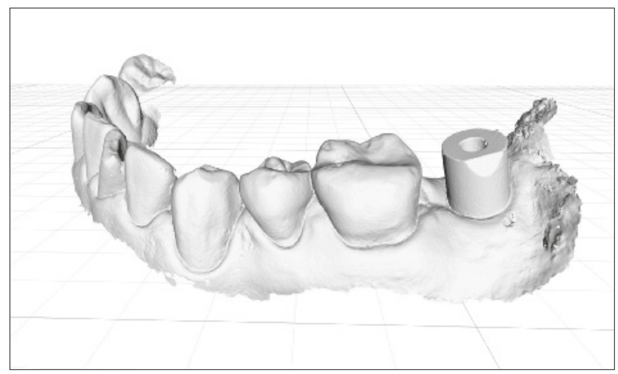

Fig 19 Surface scan ready for transfer to the CAD software.

To assist with intraoral scanning, retraction devices for lips and cheeks are often employed (Fig 18).

The data set is progressively captured in incremental images with a small field of view. The rendering of the oral cavity is constructed by the stitching together of these smaller images. To successfully merge the images, areas or objects of similarity must be found to enable the images to be successfully merged.

If multiple teeth are missing, the ability to accurately register the soft-tissue contour of the mouth can be more challenging, as the mobility of the soft tissue can prevent the scanner from recognizing sufficient points of similarity. Additionally, intraoral scanners will have a preferred path of travel and data capture that the operator should follow in order for the software algorithms to accurately reconstruct the image. Deviation from the scan path may create inaccuracies in the data captured.

When the resulting surface scan file is transferred to the CAD software, the virtual implant will be reconstructed within the image (Fig 19).

The extent of recorded information depends on the scanbody configuration, the position of the scanbody within the dental arch, and the proximity of neighboring structures (teeth and scanbodies). Studies suggest that the extent of recorded information might also depend on the scanning device itself, resulting in different values according to the precision of different systems.

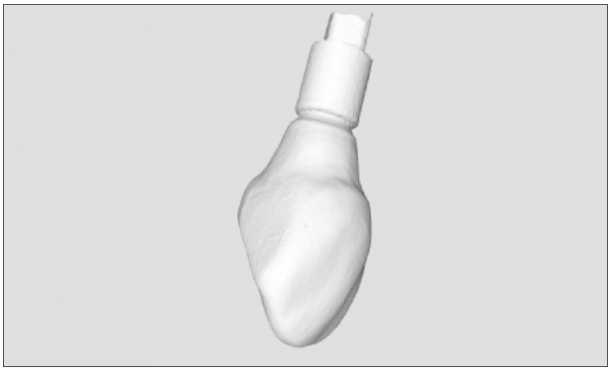

Fig 20 Scan of the provisional restoration.

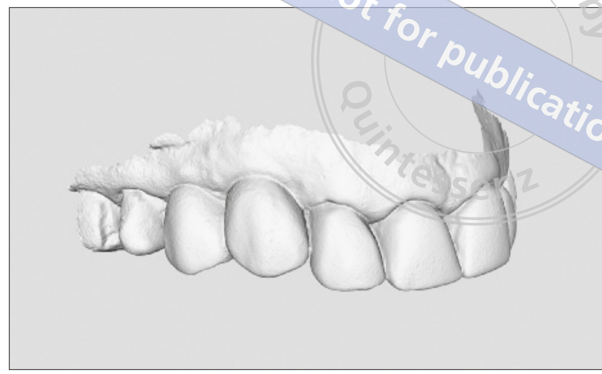

Fig 21 Scan of the provisional in place.

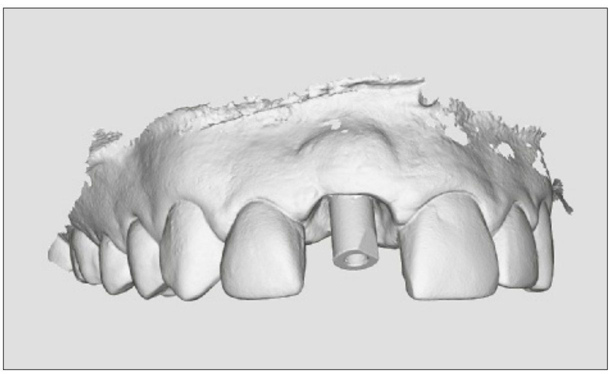

Fig 22 Surface scan of the tissue state after removal of the provisional restoration.

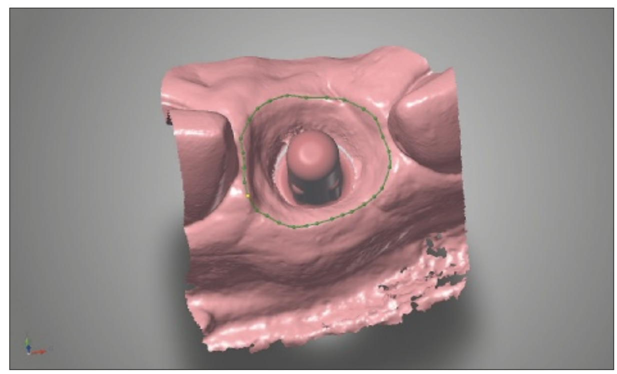

Fig 23 Customized tissue contour capture after surface scanning.

2.3.5 Emergence-Profile Scans

Tissue customization is frequently employed for implants in the esthetic zone to sculpt and shape the peri-implant mucosa prior to the delivery of a definitive restoration. With conventional impressions, this involves additional steps to create customized impression copings. With digital scanning, it is possible to directly scan the emergence profile of the customized provisional restoration (Fig 20) together with two surface scans: one with the provisional in situ (Fig 21) and one with the scanbody in place (Figs 22 and 23). Functions within the CAD software allows this emergence contour established in the provisional to be duplicated for the final restoration.

2.4 Accuracy: Trueness and Precision

Trueness and precision are often used interchangeably when describing the accuracy of digitizing the intraoral form. However, there are important differences between the two terms. Trueness is the ability of a measurement to match the actual value of the quantity being measured. However, precision is the ability of a measurement to be consistently repeated. International standards are used by manufacturing companies to allow comparison of different machines (ISO 12836:2012; ISO 12836:2015).

Since dental implants are immovable objects, implant prostheses rely on a high degree of accuracy to create a prosthesis that passively fits the implants. Any misfit in a framework for multiple implants has been shown to contribute to mechanical and biological complications (Abduo and Lyons 2013). The use of CAD/CAM technology aims to reduce the potential for misfits by reducing human intervention and the accumulation of minor fabrication errors inherent in analog workflows that include waxing, investing, casting, and polishing. For this to be realized in the CAD/CAM process, the digitization of surfaces by optical scanning must be accurate to faithfully represent the features within the oral cavity.

Unlike conventional impressions, where the material selected has inherent limitations affecting accuracy, the accuracy of detail captured is consistent and therefore the practicality of using the scanner within the mouth must be considered. Therefore, when using an intraoral scanner some physical requirements must be satisfied. If the scanning “wand” is dimensionally too large it will not effectively reach all areas of the mouth, potentially compromising the quantity and quality of the captured data (Fig 24).

Other inaccuracies in the intraoral scanning process can arise from several sources:

- In order for the scanner to capture the required areas, the light-emitting device must be able to access all areas of the dentition (Fig 25).
- Incomplete acquisition of the surface of a scanbody by the scanning device may result in failure of the software to recognize the scanbody or cause imprecise computing of the cylinder position and its geometric characteristics (Fig 26).
- Degradation in the precision of measurement of the angles between multiple scanbodies may arise from

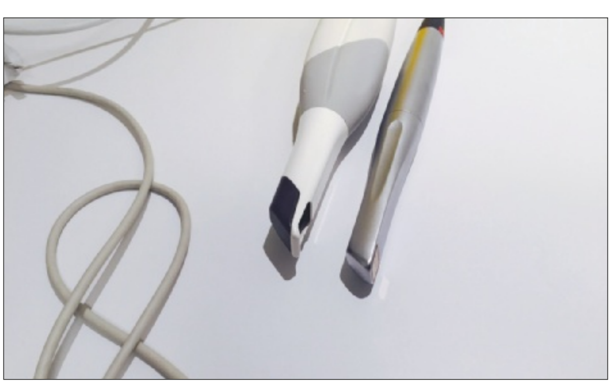

Fig 24 Two different scanner tip sizes. A larger size could limit the ability to reach certain areas of the patient’s mouth.

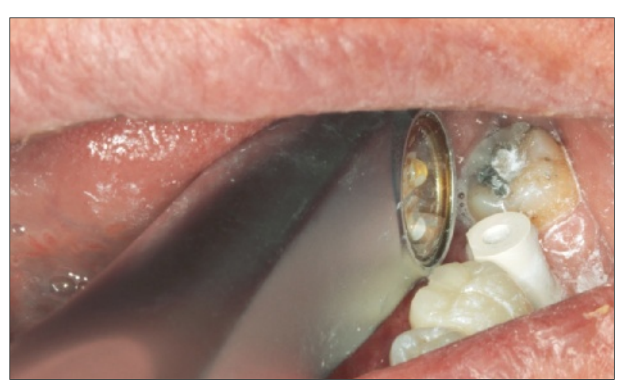

Fig 25 Positioning of the scanner tip to assist in retracting the tongue.

size differences in the scanbodies and from the algorithms used for the surface-scan reconstruction.
- Fogging or moisture contamination of the glass surface of the scanner tip can reduce the accuracy of the scan. While most systems have inbuilt heating elements within the scanner tip to reduce fogging, slow-speed evacuation is also of assistance.

2.4.1 Technique Selection

Since dental implants are immobile structures within the alveolar bone, any inaccuracy in the impression or scanning technique may result in an inadequate prosthetic fit. Intraoral scanning techniques have the potential to offer time- and cost-saving benefits to clinicians. Additionally, the peri-implant mucosal position is captured in a passive state, which allows for a more accurate location of intended cementation lines. For single-unit and short-span prostheses of up to three units, intraoral scanning is claimed to be as accurate as conventional impression techniques, but there are few studies to verify such claims (Ender and Mehl 2011; van der Meer and coworkers 2012).

When dental implants are surrounded by a deep soft-tissue collar, the length of the scanbody may be insufficiently visible through the mucosa for the optical sensor and a conventional impression followed by laboratory scanning may be advisable, as the removable tissue model may allow more accurate scanbody identification (Gimenez-Gonzalez and coworkers 2016).

Creating restorations based on sectional scans of the dental arch is possible. However, when more extensive restorative solutions are required, the clinician should make a complete-arch scan to ensure the accurate reconstruction of the clinical situation and create a restoration that harmonizes with the occlusion and functional form. Additionally, in the CAD design process, the dental technician may choose to use a “mirroring anatomy” function, which requires the contralateral tooth form(s) to be captured in the scan.

However, the lack of clearly identifiable static anatomical landmarks in the edentulous arch that can compromise the stitching together of small field of view images captured by intraoral scanners can result in positional discrepancies and inaccurate inter-implant relationships.

This may change as intraoral scanning technology improves in the future, but at present, full-arch reconstructions requiring multiple splinted implants are best captured using conventional impressions subsequently scanned with a laboratory scanner (Andriessen and coworkers 2014) (Fig 27).

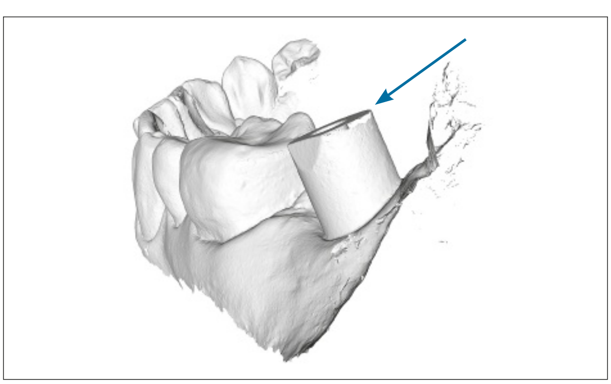

Fig 26 Void as seen on the distal surface of the scanbody. This may limit the accuracy of implant location within the CAD software. The clinician should strive to have the entire surface captured in the scan.

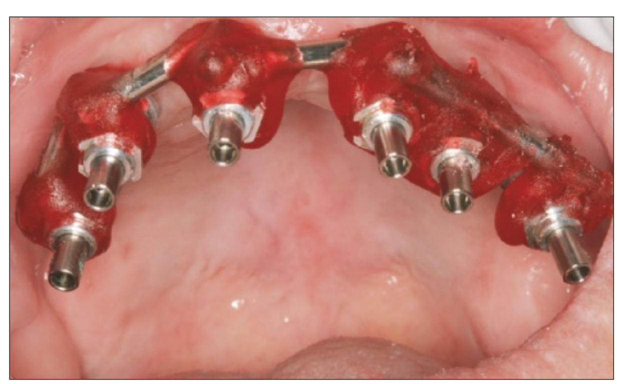

Fig 27 Full-arch implant reconstruction using a conventional analog impression where the impression copings are rigidly splinted. This provides the most accurate method of recording the implant positions in a full-arch case.

2.5 The Need for Physical Models

The dental technician may still require a model for certain stages in finalizing the prosthesis. In such situations, intraoral scanning can be used to produce models for the dental technician to complete the restoration. When a model is requested, this is usually a 3D-printed model or a stereolithographic (SLA) polyurethane die, with a holder for a repositionable laboratory analog (Figs 28 to 30).

Completely monolithic restorations are becoming increasingly popular as a means of avoiding technical complications such as fractures in a ceramic build-up, the high cost of conventional metal-ceramic restorations, and lengthy production time associated with such restorations (Joda 2017a). It is possible for monolithic restorations to be produced without the need for a working model in a direct CAD/CAM process.

Currently, monolithic materials are not suitable for use in highly aesthetic cases, where layering ceramics are required to develop appropriate translucency and staining to match the natural dentition. Additionally, when longer-span prosthetic designs are necessary or metal frameworks are used, a model is required for contact point formation and occlusal design.

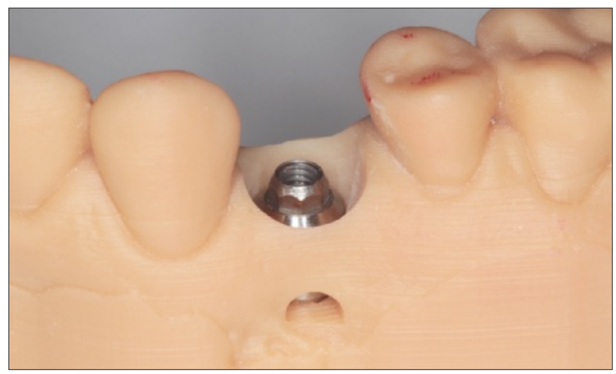

Fig 28 Abutment and repositionable analog located with a 3D-printed model. Note viewing window to confirm the repositionable analog is fully seated in the model.

Fig 29 CAD/CAM implant restoration on 3D SLA printed model used for contact point and occlusal verification.

Fig 30 Repositionable analog removed from the model and layered CAD/CAM zirconia restoration.

2.6 Concluding Remarks

- Intraoral scans are possible for a wide variety of clinical situations, but at this point they are not suitable in every clinical case.
- Models and impressions can be scanned to be loaded into CAD/CAM software.
- Working in a model-free environment is possible when using monolithic restorations. However, when producing non-monolithic or layered restorations, a working model is required.

The field of implant dentistry continues to grow, both in terms of the number of practitioners placing and restoring implants and in terms of patients demanding successful outcomes in as short a time as possible. The pace of technological changes and new offerings from implant manufacturers and allied industries are equally fast in their attempts to meet these demands, with a frequently bewildering array of potential solutions available to clinicians. This is never more so than in the field of digital dentistry, with hardware and software solutions for diagnosis, imaging, planning, surgery, impression-taking, and the computer-aided design and manufacture of intraoral prostheses.

However, we must always remember our responsibility to ensure that our treatments are carried out safely and in the best interests of our patients. This new Volume 11 of the ITI Treatment Guide series continues the successful theme of the previous ten volumes: a compendium of evidence-based methodology in digital techniques and procedures for daily practice. Written by renowned clinicians and supported by contributions from expert practitioners, the ITI Treatment Guide *Digital Workflows in Implant Dentistry* provides a comprehensive overview of various technological options and their safe clinical application.

The forthcoming Volume 12 of the ITI Treatment Guide series will address the integration and management of peri-implant soft tissue.

ITI Treatment Guide – Step by Step to Success

- For Sound Diagnostics
- For Evidence-Based Treatment Concepts
- For Predictable Outcomes

ISBN: 978-3-86867-385-2

9 783868 673852