International Journal of Computerized Dentistry

Manuscript:	IJCD-2021-69/R1 RESUBMISSION - (1114)
Title:	Digital planning protocol for functional and esthetic prosthetic treatment
Authors(s):	Mariusz Kochanowski et al.
Keywords:	CAD/CAM, CBCT, computerized dentistry, digital dentistry, digital occlusion and articulation, esthetic digital planning, Zebris for Ceramill
Type:	Case Report/Application/Lab Application

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record.

Please cite this article as doi: 10.3290/j.ijcd.b2599445

Submitted: 2021-06-05

Accepted: 2021-12-15

Protokoll für die digitale Planung für eine funktionell-ästhetische prothetische Behandlung

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Digital planning protocol for functional and esthetic prosthetic treatment

Abstract

Aim: The aim of this study was to present the different stages of prosthetic treatment planning involved in the design of an esthetic smile and improving masticatory function using CAD/CAM technology.

Materials and methods: The patient underwent the following tests and procedures: CBCT cone beam computed tomography (CS9300, Carestream, USA), intraoral scans and occlusal detection (CS3600, Carestream, USA), a portrait session (Nikon D610, Tokyo, Japan), a face scan (Bellus 3D FaceApp, iPhone XS, Apple) and registration of individual TMJ angles and mandibular movements with a Zebris for Ceramill device (Amman Girrbach, Germany). All the data were transferred to a Ceramill Mind software (Amman Girrbach, Germany) where they were integrated. The face scan and photos were superimposed on the CBCT. Scans of the dental arches were combined with the CBCT. On this CBCT basis, position of the condyles in the articular fossae was determined.. A Virtual Artex CR articulator (Amann Girrbach, Germany) was attached to the 3D object. Individual TMJ angles and mandibular movements were then introduced.

Result: A virtual patient was created in the Ceramil Mind software. The optimal shape and position of each tooth were designed into the programme The wax-up was printed using a 3D printer and a temporary mock-up and final restoration were made for the patient. In te same time, the aesthetics of the smile was improved and a harmonious central occlusion and articulation were obtained on virtual models and in in the patient's oral cavity.

Conclusion: The presented digital planning protocol allows to work out an optimal solution in complicated patient cases from a functional and aesthetic point of view.

Key words:

CAD/CAM, digital dentistry, CBCT, Zebris for Ceramill, computerized dentistry, esthetic digital planning, digital occlusion and articulation,

Introduction

The development of new technologies has given rise to new possibilities in modern prosthetics. The Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems currently in use allow technicians to create computer-aided designs and make prosthetic restorations. A CAD/CAM-based process consists of three elements: scanning the dental arhces, designing the restoration and milling it using a numerically controlled machine tool or via 3D printing of the planned restoration. Instead of taking impressions and pouring plaster models, intraoral scanners can be used to create a virtual image of the prosthetic substrate and export Standard Tessellation Language (STL) files to the CAD system. In this way, accurate virtual 3D models are made.[1] In contrast to the analogue production of wax prototypes of restorations using plaster models, in CAD/CAM systems prosthetic restorations are designed with CAD software.[2–4] Instead of the laboratory production of restorations, the designs processed with CAM software are transferred to milling machines or numerical printers, that produce the restorations from prefabricated materials.

There are programs that, based on photos of the patient's face and scan of his dental arches, allow you to design a perfect virtual smile for the patient. Unfortunately, so far these programs have not been able to correctly position the scanned models with the cranium and TMJ of the patient. Virtual articulators could not be used to adapt the new tooth shapes to occlusion and articulation.

Nowadays, the opportunities available for obtaining digital patient records are enormous Cone Beam Computed Tomography scan (CBCT) with a variable Field of View (FOV) and low doses of radiation allows to obtain a high-resolution image of the craniofacial bone.[5] After their conversion, Digital Imaging and Communications in Medicine (DICOM) data can be imported into CAD software.

Additionally, 3D scans can be made of the patient's face and skin points can be registered.[6,7] Electronic facebows and mandibular movement registration can be used in place of their analogue equivalents. The data thus obtained can be entered into a virtual, fully adjustable articulator.[8] All the data can be integrated in a CAD software so as to create a complete virtual image of the patient.

Objective

The aim of this paper was to present the different stages in a digital prosthetic treatment protocol using CAD/CAM technology in order to design an esthetic smile and improve masticatory function.

Treatment protocol

A 22 year-old female patient sought treatment to improve her smile esthetic. A physical examination revealed no systemic diseases or injuries affecting the stomatognathic system. The patient's medical history revealed that she had worn a fixed orthodontic appliance due to the overbite and the labial displacement of tooth 13. An intraoral examination revealed the presence of a fixed retainer on the lingual surfaces of teeth 33 to 43; teeth 28, 38, 48 and 14 were missing, having been extracted for orthodontic reasons. A physical examination showed a diastema in the anterior segment, displacement of the dental midline, negative space when smiling, unsightly shaped front teeth, the suboptimal smile line, suboptimal occlusion and no canine guidance. A class I canine, Angle class II was noted. No clinical changes were identified in the periodontium or the mucosa, and there were no abnormalities in the temporomandibular joints.

The prosthetic treatment plan was based on a digital protocol, which consisted of 4 main stages:

I Digitization of the patient's data,

II Importing the data into a CAD/CAM system,

III Creation of a virtual wax-up, printing the wax-up with a 3D printer, IV Intraoral mock-up creation on the basis of the printed wax-up.

Stage I – Digitization of the patient's data,

During the first stage of the diagnostic process, the following procedures were performed: computed tomography using CS9300 (Carestream, USA), intraoral scans with CS3600 device (Carestream, USA), a photo session with a Nikon 610D camera (Nikon, Japan), a face scan using Bellus 3D FaceApp (Apple, USA) a Ceramill Map 600 scan with para-occlusal bite forks (Amann Girrbach, Germany) and individual TMJ angles and mandible movements registration using a Zebris for Ceramill device (Amann Girrbach, Germany).

A cone beam tomography of a cylindrical volume was performed using the CS9300 device (Carestream, USA) with 17x13.5 variable field of view. This provided the basis for assessing mandibular condylar processes in maximum intercuspation (Fig. 1). This allows to determine the exact position of the maxilla in relation to the facial skeleton and the mandible hinge axis. These tests confirmed that the centric relation was the same as the maximum intercuspation, and that there was no signs of inflammation in the periapical tissues or paranasal sinuses.

The CS 3600 intraoral scanner (Carestream, USA) was used in a continuous scanning mode. The upper and lower dental arches and surrounding soft tissue were scanned. Occlusion was detected with a lateral scan (Fig. 2). Digital 3D models of the patient's teeth were obtained in the form of STL files.

The patient's portrait session was shot using a Nikon 610D camera (Nikon, Japan), a Nikon105 lens and Visco 300w flash lamps with 40x60 softboxes. The session consisted of extraoral and intraoral photos (Fig. 3). The extraoral photos covered the following positions: frontal view, capturing the patient's smile phases (1- rest, lips joined, 2 - slight smile, 3 - broad smile 4 - strong smile, almost "grinning"), at an angle of 45 degrees together with a broad smile, the patient's profile together with a broad smile, and frontal view with lip-cheek retractor. The intraoral photos: upper dental arch, lower dental arch, dental arches in static occlusion - frontal view, dental arches in static occlusion – right profile, and dental arches in static occlusion – left profile. In addition, a short video was recorded with the patient during the interview. This was used to assess "frame by frame" the patient's natural manner of speech, the exposure of the teeth and the arrangement of the lips. Shots were selected and used during the subsequent design stages. All the photographic documentation of a case was taken from a distance of about 1 m to avoid distortion.

The next step was to perform a scan of the patient's face using Bellus 3D FaceApp software (Apple, USA) installed in a phone (iPhone XS, Apple, USA), to enable the alignment of the CT scans with face soft tissues (Fig. 4). The face, including the auricula, was filmed on a smartphone as the patient moved her head up and down, as well as to the sides.

An electronic recording equipment – a Zebris for Ceramill digital facebow (Amann Girrbach, Germany) equipped with a sensor and optical sensors – was used to record the position of the maxilla and mandible in relation to the temporomandibular joint. The device was positioned on the patient's head parallel to the interpupillary line and set on a nasal support. The sensor was placed in turns in the left and right external acoustic pores as well as in the infraorbital points and their positions were recorded. Based on that, the software positioned the facebow in relation to the facial skeleton according to the Frankfurt plane. The bite fork was then attached to the upper arch with a LuxaBite (DMG) (Fig. 5). The patient made a few opening and closing movements with her mandible. The device recorded the position of the jaw in relation to the temporomandibular joints. It registered the angles and movements of the mandible. The para-occlusal bite fork was placed on the vestibular surface of the lower teeth and attached to the teeth with O-Bite hard silicone (DMG, Germany). It is important to make sure that the weight and elements of the fork do not interfere with the patient's occlusion and occlusal articulation. The patient made forward and sideway movements, which were simultaneously recorded on the device (Fig. 5). The sagittal condylar path inclination, the Bennett angles in the left and right joints as well as the mandibular path were all recorded.

The bite fork used to record individual TMJ angles and the mandibular movements was scanned with a Ceramill Map 600 laboratory scanner (Amann Girrbach, Germany). The bite fork scan was one of the elements enabling the superimposition of all the elements in the virtual software.

Stage II – importing and integrating the data in a CAD/CAM software

All the data were imported to the patient's medical record created in the Ceramill Mind CAD/CAM software (Amann Girrbach, Germany). The intraoral scans of the upper and lower arch were imported to the platform as .stl files. The virtual dental arches were positioned in the maximum intercuspation on the basis of a lateral scan in habitual occlusion. All the teeth in the upper and lower dental arches were marked. The Anatomic Pontic design option was selected.

Selected photos of the patient's face were superimposed on scans of the dental arches: face in a spontaneous smile with spread dental arches and face with applied retractors. The elements were adjusted by selecting a few reference points in both files: on the cusps of teeth 23 and 14 (Fig. 6). The lips were outlined and the interlabial space was removed from the photo.

The face scan (skin element) was combined with a mesh generated from the CBCT examination (bone elements) and the dental arch scans (Fig. 7). Surface bony landmarks were used as reference points: the glabella (the most forward-lying point in the lower part of the forehead between the browbones), the orbitale (two points lying at the intersection between the lines descending from the centre of the pupils when looking into the distance and the lower edges of the orbits) and the auriculare (centres of the auricular openings) [9]. The tooth scans were manually joined with the CBCT mesh using the reference points denoting the cusps of individual teeth. Thus it was possible to obtain the virtual anatomical position of the temporomandibular joints in the facial skeleton.

The Zebris for Ceramill bite fork scan was imported to the Ceramill Mind software. It was connected via selected points with the scan of the upper dental arch. As a result, the dental arches were positioned in relation to the axis of rotation in the temporomandibular joints. The TMJ angles and mandibular movements were automatically loaded from the Zebris for Ceramill register into the Virtual Artex CR (Amann Girrbach, Germany) virtual articulator. The articulator has the following characteristics: an individually set sagittal condylar inclination angle within the range of -20˚ to + 60˚ and an individually set Bennett angle within the range of -5˚ to + 30˚. The immediate lateral shift from 0 to 1.5 mm on each side, protrusion from 0 to 6 mm and retrusion from 0 to 2 mm can be set, with adjustable distraction of the mandibular head. The following values were recorded for the patient: a sagittal condylar inclination of 6˚ on the left side and 10.4˚ on the right side, Bennet angle 10˚, immediate lateral displacement 0.6 mm (Fig. 8). The 3D image of the virtual patient was thus expanded to include individual mandibular movements.

Stage III – creating a virtual wax-up and printing the latter on a 3D printer,

To design the smile esthetics the Ceramill M Smile module (Amann Girrbach, Germany) was used (Fig. 9). The virtual teeth design phase began with the superimposition of the midline, interpupillary line and the incisal line of the upper teeth on the photographs. The midline passes through the following points: *trichion, glabella, nasion, subnasale, labiale superius, labiale inferius, pogonion, gnathion.* Our aim is to achieve the consistency of the midline of the face and the midline of the smile. The interpupillary line is the line connecting the patient's pupils. It should be parallel to the horizontal plane and perpendicular to the midline of the face. The incisal line of the upper teeth passes through the incisal margins of the upper central incisors. It should be parallel to the interpupillary line. The line of nasal alae, the line of the corners of the mouth and the smile curve, as well as the lines of the upper and lower lips were all plotted. The lips are the natural framework for a smile. The width of 5 anterior teeth (between canine cusps) was pre-determined in accordance with the proportions of the face, making sure they fit between the nasal alae lines, while the length of the teeth was designed so that they would reach up to the lower lip line.

Based on the described lines, a mesh was generated, maintaining the proportions of the central incisor, lateral incisor and canine at 100:65:50 (Fig. 10). The shape of the teeth was selected from the library of natural teeth, taking into account the patient's sex, age, facial shape and facial features. Each tooth was manually positioned [10]. As the patient did not have a gummy smile, the line of the gingival zenith overlapped with the line of the upper lip.

In this esthetically designed dental arch, the occlusion and articulation were optimized. The virtual articulator made it possible to observe the occlusal contacts of the opposing arches during occlusal and articulation movements (Fig. 11). By appropriately adding or subtracting virtual tooth structures, a fully functional customised wax-up design was achieved.

The design of the lower and upper dental arches were printed on the NextDent 5100 printer (3D Systems) (Fig. 12). The models were washed in an ultrasonic cleaner with a 90% isopropyl alcohol solution, dried with compressed air and post-cured with a UV lamp.

Stage IV – intraoral mock-up creation.

Based on the printed wax-up models, a technical silicone index was made using vacuum forming from a two-component addition-curing silicone Fegura Sil (Feguramed). Luxatemp (DMG) was introduced in the index and a mock-up was created intraorally. The patient's diastema was closed, the midline of the dental arches moved closer to the midline of the body, the shape of the teeth was in harmonyn with the face, and the length of the teeth was adjusted to the lower lip line when smiling. The correct centric occlusion as well as incisal and canine guidance were restored (Fig. 13).

The final restoration turned out to be minimally invasive composite venners made on upper anterior teeth and occlusal veneers on upper posterior teeth. The procedure was performed using flowable composite shade A2 (G-aenial Universal Injectable, GC Corp, Tokyo, Japant) in flow injection technique due to the patient's age. This technique did not require teeth preparation and provided improvement of both esthetic and function. Flowable material was placed in the customized 3D-printed transparent keys based on the digital wax-up (Fig. 14). Final work fitted perfectly with facial apperance and occlusion (Fig. 15). The patient was satisfied with her esthetic smile, improved symmetry of the dental arches and the shape of the teeth, as well as comfortable occlusion and occlusal articulation.

Summary and discussion

The greatest advantage of digitally planning the shape of teeth in CAD/CAM systems is the possibility to simultaneously assess esthetics and function.

The analogue prosthetic treatment protocol is prone to error due, among other things, to the properties of the materials used, e.g., the impression materials, plaster, waxes. [11,12] These problems overlap with technical errors related to the registration using an arbitrary facial arch where the mandibular hinge axis is approximated by the position od the external acoustric pores (pori acustici externi) as well as to the approximate patient's mandibular movement paths simulated in the articulator. As a consequence, the occlusal equilibration often took place intraorally. Working with the models mounted in a traditional articulator, the technician did not see the image of the patient's face, the pupillary line, the nasal alae lines, the position of their lips, smile, etc. As a consequence, the technician could not plan esthetic restorations in a predictable way. [13]

Currently, it is possible to plan an aesthetic smile in a patient based on programs using digital models and photos of the patient, e.g., Digital Smile Design (DSD), Smile Designer Pro (Tasty Tech, Canada), DTS (DTS, India), IvoSmile App (Ivoclar Vivadent, Lichtenstein), Smile Clouds (Smilecloud SRL, Romania). However, they lack a functional planning module.

Only by consolidating all of a patient’s data in CAD/CAM software platforms, such as Ceramill Mind (Amann Girrbach, Germany), Exocad (Align Technology, USA), or Romaxis (Planmeca, Finland) enables simultaneous planning of aesthetics and function in prosthetic treatment. Based on the photos of the face, using the Ceramill M Smile program, the patient's perfect smile was designed. The improved tooth shapes were changed simultaneously on virtual 3D models. The patient's craniofacial CBCT allowed for accurate positioning of the hinge axes of the mandible. The addition of a virtual articulator made it possible to adjust the shape of the teeth to the occlusal movements of the patient's jaw. Virtual project has been printed. On its basis, the patient's teeth were restored using the flow injection technique. This project may be used in the future to perform works in the CAD / CAM technique. The presented digital planning protocol allows to work out an optimal solution in complicated patient cases from a functional and aesthetic point of view.[14,15]

Acknowledgments

We would like to express our special thanks to *Natrodent Prosthetic Laboratory* who significantly contributed to results of our work by providing essential devices and continued supported this project.

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Illustrations:

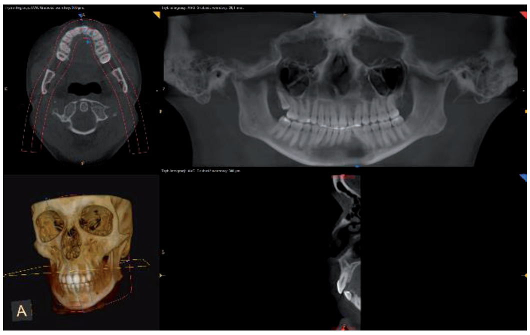

Fig. 1 CBCT preformed with CS 9300

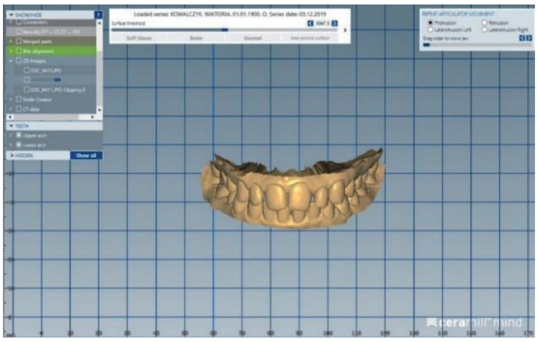

Fig. 2 The virtual scans of upper and lower dental arches positioned in the maximum intercuspidation.

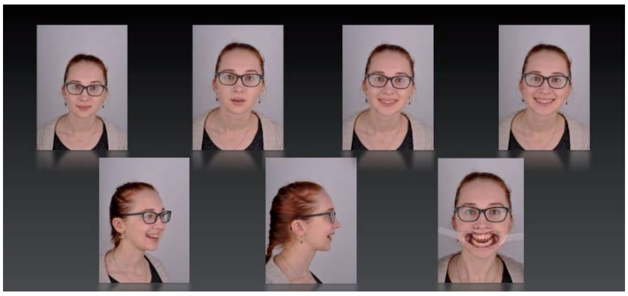

Fig. 3 Photographic protocol, preformed in photo studio before treatment

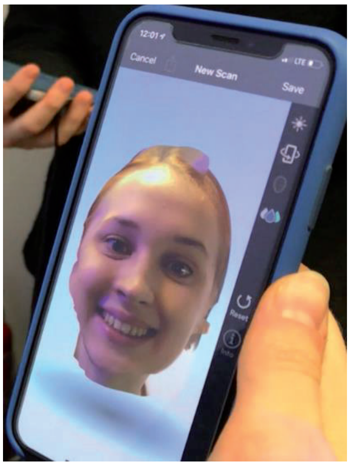

Fig. 4 Face scan performed with Bellus 3D FaceApp

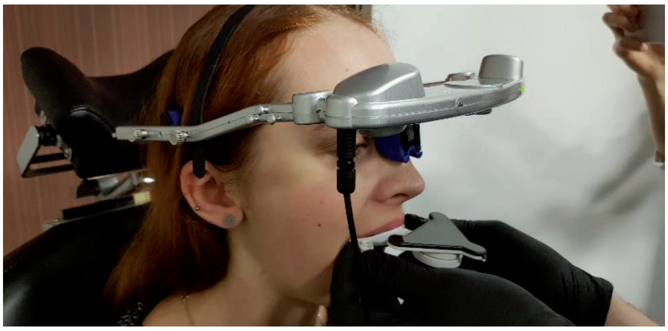

Fig. 5.

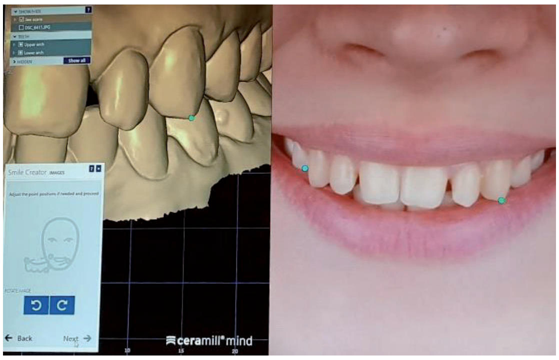

Fig. 6 Photo with reference points on teeth 23 and 14

Fig. 7 Patient photos combined with CBCT mesh and face scan

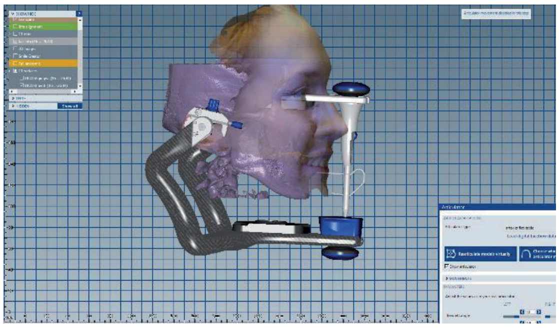

Fig. 8 CBCT scan, face scan, bite fork scan and dental arch scans uploaded into the Virtual Artex CR digital articulator (Amann Girrbach, Germany)

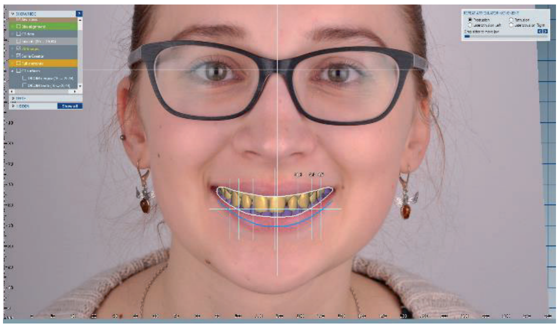

Fig. 9 Virtual planning of the esthetic smile - a generated graphic grid overlaid on the patient's photo in the Ceramill Mind program.

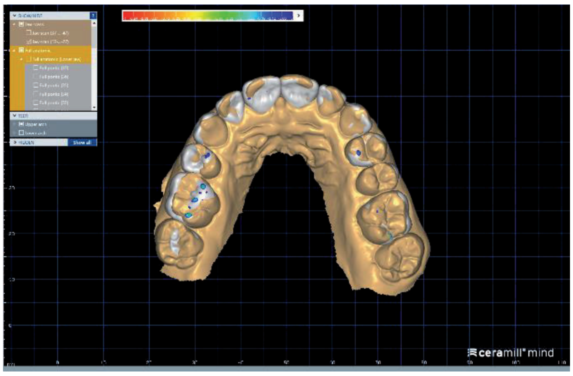

Fig. 10 Digital optimization of occlusion and articulation of designed smile

Fig. 11 Wax-up models printed with 3D printing technology

Fig. 12 Upper dental arch's mock-up

Fig. 13 Motivational portrait session with mock-up (Natrodent Prosthetic Laboratory)

Fig. 14 Two customized 3D-printed transparent silicone keys.

Fig. 15 Portrait session with final smile (Natrodent Prosthetic Laboratory)