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28. THE SOPHA DENTAL CAD/CAM: 2 YEARS OF RESEARCH IN USC SCHOOL OF DENTISTRY

François Duret, DDS, DCD, DSO, Dt D'etat, MS, PhD

Today, everyone should know what CAD/CAM is (Computer Assisted Design and Computer Assisted Manufacturing). There are now a number of systems commercially available or nearing completion. However, only a few of them merit the name CAD/CAM, and there is only one that is commercially available today. This paper will briefly discuss each system that at least uses a digital system, a manufacturing system, or both. An initial overview will be presented, and the further elaboration on one system will be made.

CELAY SYSTEM

The Celay system is composed of two parts, one that reads with a mechanical sensor, a tracing device, and the other meant for milling with the help of a 4-axis microbilling machine. It is actually a copy milling machine similar to that used for making keys.

PROCERA

The Procera system is a duplicating and milling system using a mechanical sensor reading or tracing technique, a pantographic milling process similar to that of Celay, and a second milling process using electroerosion.

TITAN

The Titan system includes a mechanical sensing unit, a classical CAD station, and a numerically controlled milling machine.

CEREC

The Cerec system is a compact system consisting of a CCD camera, an image-processing station associated with a Macintosh-typed gray scale VDT, and a 2.5-axis micromilling machine using an hydraulic drive.

DEVELOPMENTAL SYSTEMS

DentiCad

There are two systems under research and development, the DentiCad and the Japanese system. Only a small amount of information on these systems is available. Dr Rekow's DentiCad system has not been evaluated by anyone but Dr Rekow, nor has the system been displayed at a conference or had a controlled evaluation. Slides of the system and numbers unsupported by data have been presented. I do not agree with Dr Rekow's position concerning CAD/CAM control. She has stated that the best method of ascertaining the quality of a CAD/CAM system is to ask some precise questions, and for this she has proposed a list of such questions. I disagree. Her questions are unnecessarily complex, and the answers are more disturbing than merely controlling the machine.

The best way to evaluate any system, without having to rely on claims and unsupported statements, is to bring a cast with a prepared tooth, and ask to have a crown made in your presence and in real time. Then it would be very easy to know the true level of development. One must never accept a demonstration with a model from the manufacturer or any work done without the evaluator being present. It is far too easy to predesign and not work in real time.

Japanese Research

The Japanese system is a very interesting machine, however probably little is known about the true level of development.

SOPHA BIOCONCEPT

In the concept of the dental CAD/CAM system there are three steps that relate directly to traditional dental technology:

1. Make the impression or, using CAD/CAM, make the optical or contact palpation print.
2. Build the crown in wax, or using the CAD/CAM, design it on the screen.
3. Cast the crown, or using CAD/CAM, mill it.

The Sopha Dental CAD/CAM system is not new, but, rather, it is the oldest one. However, it is a new beginning (the Duret system is now the Sopha Dental CAD/CAM), with a new company (Sopha Bioconcept) in a new location (California).

This presentation will primarily focus on the Sopha Dental CAD/CAM system and how it is used to fabricate a crown. As previously noted, there are three steps, impression, CAD, and CAM.

Preparation of the Impression Zone

In preparation for imaging, there are three specific steps: (1) obtain an occlusal record, (2) coat the surfaces to be imaged, and (3) place correlation spheres. For the occlusion, a very traditional method is used. The record is a classic interarch record. An interarch impression is made in a stable material, such as silicone, trimmed, and placed on the teeth including preparation to be imaged. This gives us the anatomy of the opposing teeth in relationship to the teeth that are to be restored and the associated correlation sphere.

The coating that is placed on the teeth to be imaged and the interocclusal record is a thin film that uniformly covers the surfaces to avoid specular reflection.

Three correlation spheres, made especially for this purpose, permit the correlation of various views made by the practitioner. These spheres are placed on the facial and lingual surfaces and become the orientation points by which the computer can correlate multiple images. With CAD/CAM it is necessary to have several views because not all the sides of a preparation are visible in any single picture.

The Impression

The impression is divided into two parts: the recording of the various views and definition of specific features by the operator. These features are needed by the computer to allow the CAD to work with maximum efficiency.

Obtaining the Views

Using an optical probe, a type of camera, the practitioner makes a series of pictures of the preparation, from different angles. Up to 16 different views can be made according to the operator's choice but some views are obligatory. These are the occlusal view on the preparation side (camera in the occlusal plane) and the occlusal view of the interarch record (which is the recording of the opposing teeth). The other views will be used to gather the maximum amount of information (of points) increasing the precision of the impression. The correlation spheres must be clearly visible in each view.

The practitioner records an average of 10 views to create a crown. This is estimated to take about 3 minutes of work in the mouth. The practitioner may then either continue the work or give it to a technician. For one view the author uses approximately 20% of the active surface, meaning 50,000 pixels per view or 500,000 pixels for 10 views. More important than the number of pixels, however, is the quality of the correlation between each view—the accuracy with which the individual views are joined together to form a three-dimensional image.

Interactive action. Using a mouse, the operator indicates the position of the three correlation spheres as well as the location of a certain number of fundamental points for the construction of the future crown. The finishing line of the preparation is defined and the exact position of grooves on the occlusal and opposing views is marked.

On the occlusal view a line connecting the greatest faciolingual diameter of the adjacent teeth is drawn, proximal contact areas are defined, and the general positions of the cusps and grooves are indicated. The positions of the cusps and grooves are defined on the opposing view. On the other views the finishing line is traced as precisely as possible. Magnification ("zoom") of any section is possible for enhanced definition.

Such procedures are typical and, although software can be used to automatically find the cusps, spheres, etc, I think that it is better for the operator to choose these.

Three-dimensional definition and modeling of the impression. The three-dimensional definition and modeling are automatic. The three-dimensional relationship of each view is calculated and the views are correlated. This calculation is brief (between 2 and 3 minutes). In this step the spatial position of each of the pixels making up the surface of the views and reference points is calculated. Until this point these views were in the two-dimensional memory of the charge-coupled device (the storage element of the camera). The operator does not have to intervene except at the end of the calculation to remake any view that may have been rejected because of poor quality. The modeling treatment, development of a three-dimensional virtual model, consists of uniting the views based on the known and measured position of each of the three spheres and then blending them into a single group of points.

At the end of this operation the spatial modeling of the tooth preparation in relationship to the adjacent and opposing teeth has been accomplished. The position of the reference points and lines in the interactive phase has been obtained. Approximately 15 minutes are necessary to make the impression and to complete the interactive work and computer calculation.

CAD

The CAD step is a decisive one because it permits the design of the future crown using the information derived from the impression and from the computer's library of theoretical teeth. At this stage the operator has the choice of working quasi automatically (2 or 3 minutes) or to proceed interactively. In the automatic mode one goes directly to the last step, the work of the milling machine, but the crown may be modified using special software (correction software) if desired. This way is very comfortable but if any errors have been made, they are difficult to correct.

At this time it is better to use the manual, interactive, method. Based on specific dental software, the program allows the user to manipulate the design to provide an indisputable clinical character, specific to this crown for an individual patient. The menu must be carefully followed and each step encloses a submenu that allows the user to detail or modify the general results obtained. There are five general menu steps:

1. Internal design
2. Relationship to the surrounding teeth
3. Calculation of the crown
4. Occlusal modification
5. Correction of any of the previous features to provide the optimum design

Internal. The definition of the internal surface is the first step in creating the future crown. The preparation is displayed and the finishing line has been defined. With the zoom function it is possible to see certain details of the preparation's occlusal and axial surfaces and the finishing line. If any part of the margin line is not acceptable, a three-dimensional cross section can be made and a view normal to the area in question is displayed. This allows a more precise outline of the margin and axial surface and offers a precision not possible with the traditional die.

The last step of the internal menu is the choice of the desired cement space. Three values are possible: one corresponds to the dilatation at the occlusal surface level, another corresponds to the horizontal dilatation, and the third or basic height allows the user to define an area surrounding the finishing line that will not undergo any dilatation.

Environment. It is during this step that the cusps of the adjacent teeth, the height of greatest contour, the position of the grooves, and the contact zones of the future crown are all defined. All of these lines constitute a type of box in which the tooth from the computer library of teeth will be re-formed to the desired morphology, a morphology that each user can personalize.

Calculation of the crown. This is a very important step in the method. Even though it is entirely automatic, it allows control of the revision of the theoretical tooth that has been drawn from the computer library and clinically adapted to the patient's individual morphology.

Occlusion. This is the second important step in CAD. The static occlusion of the tooth is developed in two steps: placing the cusps and opposing fossae of the opposing teeth in their corresponding relationships with the cusps and fossae of the crown and defining the proper cusp height.

With the information from the Access articulator (please refer to Chapter 13), it is possible to adjust the cusp angle and the direction of grooves and to automatically correct any interference between the crown and the opposite teeth.

Correction. One of the first menus given to CAD/CAM users was the correction menu. In this menu are numerous possibilities for modifying the crown obtained from the library, from a simple displacement of a so-called surface knot point that allows the user to increase or decrease the outline form of the crown, just as if wax were being added or removed, to modify the cusp angle of the crown in function.

At the end of these eight successive steps, which require approximately 6 minutes depending on the user's experience (time reduced to 2 to 3 minutes in the automatic phase). Having validated the definitive form of the prosthesis, the crown (or any other similar restoration if the software exists) is ready to be machined.

Milling the Restoration—CAM

The next-to-last step in creating a restoration is milling the unit in a material prepared specifically for this. It is done by a machine tool with numerical controls. This step is completely automatic, and no operator intervention is required. The external and internal of the restoration are all completed automatically.

CAD/CAM materials. Of course, many traditional materials can be used in CAD/CAM. The first ceramic was produced by Vita for the Cerec system (Siemens), machinable Dicor has been adapted for all forms of CAD/CAM, and various new Japanese ceramics or resins are being used. These materials remain, for the most part, homogenous and isotropic. The fact that they have been adapted for CAD/CAM is the indisputable proof of a renewal in this area in which there has been no major change since the first ceramics or the first filled resin of Bowen were made available.

All of these materials are presented to preformed blocks whose conditioning depends essentially on the device used. In most instances, and to avoid unnecessary expense, the major part, the prosthesis that is to be fabricated, occupies only the center of the block. This is the area where the milling of the crown occurs. In the Sopha Bioconcept system the crown may be made in a composite material, machinable Dicor, or a metal such as titanium. The actual milling, except for the periodic replacement of tools or the placement of the material's preformed block of material, is entirely automatic. The machine tool has a precision of nearly 0.01 mm so it is impossible to manually operate this type of robot.

The milling is done in successive steps using a specially designed 3.5-axis milling machine. We begin with the internal surface to ensure a maximum precision. After rotating the block 180°, the occlusal and axial surfaces are formed. The margin area is refined and the completed restoration is removed manually. The tools are automatically changed during the milling process.

Characterization. The characterization or coloration, of the prosthesis, is the final step in this procedure. It is done manually but will no doubt become automatic in the next few years. We can use a coloring kit (such as the Dicor kit) containing the various colorants necessary for this work. Several colors of resin luting material can result in a color generally close to basic colors of all the traditional shades.

Different restorations can now be created using CAD/CAM and others will be possible in the near future:

Inlay. The prototype inlay was made 3 years ago. The software for inlays will be ready in 1992.

Fixed partial dentures, veneers, and implants. All of these can be made but before attempting such restorations for patients, as opposed to research, specific software must be developed and controlled clinical use must be completed.

Time and Accuracy

Data on time. These results are the product of almost 3 years of work at USC. In 1987 it was necessary to work for more than 10 hours to obtain a crown from the impression. In 1988 the time was 3 hours. By 1989 it was 1.5 hours and now it is 1 hour or less. The results are obtained after having made over 4000 crowns. I, personally, require 35 to 50 minutes, because of my intimate understanding of the system. Also, remember that another crown can be designed while the first is being milled.

Data on time evolution. The best reduction of time was obtained during the impression modeling (from the original 8 hours to the present 15 minutes—progress as the result of 4 years of work). However, it is presently difficult to reduce the time required for CAM.

Accuracy. The evaluation of accuracy has been the result of a large study of the controls:

> Dr Jack Preston prepared 10 teeth by using different finishing lines. My technician and I made the crowns by CAD/CAM and Dr Preston luted the crowns and embedded and sectioned the units. Each person worked independently, without interference or artificial alteration of routine procedures. I believe that this was a scientific approach to defining the capabilities of the Sopha system.

The theoretical accuracy of the first step, the optical print, is 20 to 30 μm. The potential accuracy of the CAD is 5 to 10 μm, and the CAM accuracy is what can be measured, not what it might be imagined to be:

- In 1988, the result was not good (approximately 50 to 250 μm).
- In 1990, the result was better (close to 100 μm). The problem was at the finishing line (250 to 300 μm).
- Now, in 1991, the result is 0 to 50 μm at the margin, 200 μm at the internal aspect of the shoulder (and only there), but under 80 μm everywhere else inside the crown.

It is with pleasure that this documentable information, derived from experimental work, is presented, knowing that it is not necessary to simply rely on a theoretical discussion.