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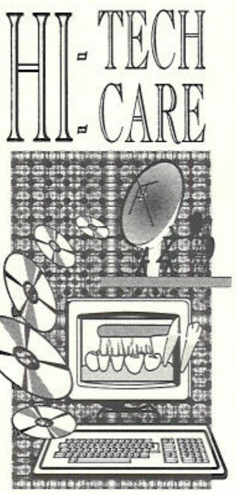

The Practical Dental CAD/CAM in 1993

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ABSTRACT

For three years now, it has been possible to find a number of dental CAD/CAM systems, i.e. systems that can produce dental prostheses with robots or computers, on the market.

These systems use palpation devices or cameras to make impressions. They either transmit the data to produce the die, the counter die or some intermediate elements directly, or use the possibilities of the computer to reconstruct the most simple pieces or the most complex prostheses on a monitor. In the latter case, CAD/CAM systems – in the full sense of the word – produce a model on a monitor before manufacturing the prosthesis.

According to this study, all the systems belong to the same family but their performances as well as their costs and their clinical testing vary considerably. A more detailed analysis would therefore be required.

Nevertheless, the CAD/CAM remains the only known prosthetic alternative for the future.

Key Words: Prosthesis, Computer, CAD/CAM, Classification, Handling, Performances

Introduction

Of all the new technologies available to dentists today, none is more likely to drastically change the practice of dentistry in the 21st century than the dental CAD/CAM.

Because it allows volumetric analysis results to be processed as numerical data; because these data can then be manipulated not only by the human mind but also by advanced computer systems, such as artificial intelligence; and, lastly, because it has a machining or manufacturing system that is non-specific to one kind of material, CAD/CAM has introduced a vast experimental field to dentistry.

It is not at all ludicrous to think that it will soon be possible to handle both the most simple diagnostic analyses and the most complex prosthetic manufacturing processes with CAD/CAM, using materials that will be absolutely revolutionary, intelligent and structure-oriented like the tooth.

All too often, however, the use of the dental CAD/CAM has been limited. This technology has been presented as a prosthetic manufacturing technique because this aspect of its development has been the most spectacular. Since its inception, however, CAD/CAM has been rated at a very high technological level, and its usefulness has certainly not been restricted to prosthetic reconstruction – a fact that many new comers in the field have failed to notice.

Even the first report on CAD/CAM, published in 1973,[1] made it clear that the optical impression technique, or dental CAD/CAM, encompasses all methods of analysis, including diagnosis and treatment, working in space, and developing means of measurement that are preferably optical.

In her historical study,[1-3] Rekow forgot to mention that this technology comes from Europe and was developed with the ambition to really use numerical data for other purposes than the simple production of a metallic object. Tribute must be paid to two great researchers, Altschuler and Swinson,[4-7] whose breakthrough experimental attempts in CAD/CAM were so similar to the work Gisy did in on the dental articulator in 1930.[8]

In 1973, the general rule of thumb was to consider every medical treatment as a discriminative analysis (eventually followed by correction) of the group of static and dynamic volumes that form the human body. Logically, the next step in this process was to add scientific precision through the use of mathematical investigation methods. There was only one major step to make forward in this regard, but it took 20 years of struggle, hope and disillusionment before it could be taken.

This step was so large that the optical impression method known today as the dental CAD/CAM, while not exclusively a procedure to make prostheses, is almost always perceived as such. We will explain this procedure here, dealing only with the machines already on the market or in development, and dismissing all the supposedly existing procedures that no one has been able to control as of yet.

1. Definition

1.1 Basic concept

The traditional method used to make dental prostheses is limited due to its means of data collection (impression), transport (model, die, casting flask, etc.) and final materialization (casting).

This method is based on the principle of capturing certain volumes, specifically those of the preparation and its environment, with an impression paste. These volumes are then transferred to a plaster model, which in turn is used to transfer them to other models until a prosthesis (the ultimate model) is finally made.[9-10] The original data, i.e. the volumes of the mouth and teeth, are always being stored and transferred in a material form. Although it is easy to work with these data, distortions may occur due to shocks, thermal volumetric variations and other errors.

CAD/CAM, on the other hand, is based on the principle that the data (or impression) collected from the patient's mouth must be digitized as quickly as possible. In effect, digitization allows the clinician to avoid most if not all of the hazards associated with the use of material impressions to collect data (on the spatial form of the teeth, for example) such as humidity or temperature, or simply a lack of experience, all of which are impossible to control.

To reproduce the patient's mouth using CAD/CAM, the clinician relies on a known volume depicted on a computer monitor, and not on a plaster or wax model. The important thing with CAD/CAM is to take the x-y-z coordinates of all the elementary points that form the surface of the patient's mouth. In order to avoid all unwanted fluctuations, the clinician only uses actual dental material at the final stage of treatment, which is often the production of the prosthesis (**Fig. 1**).

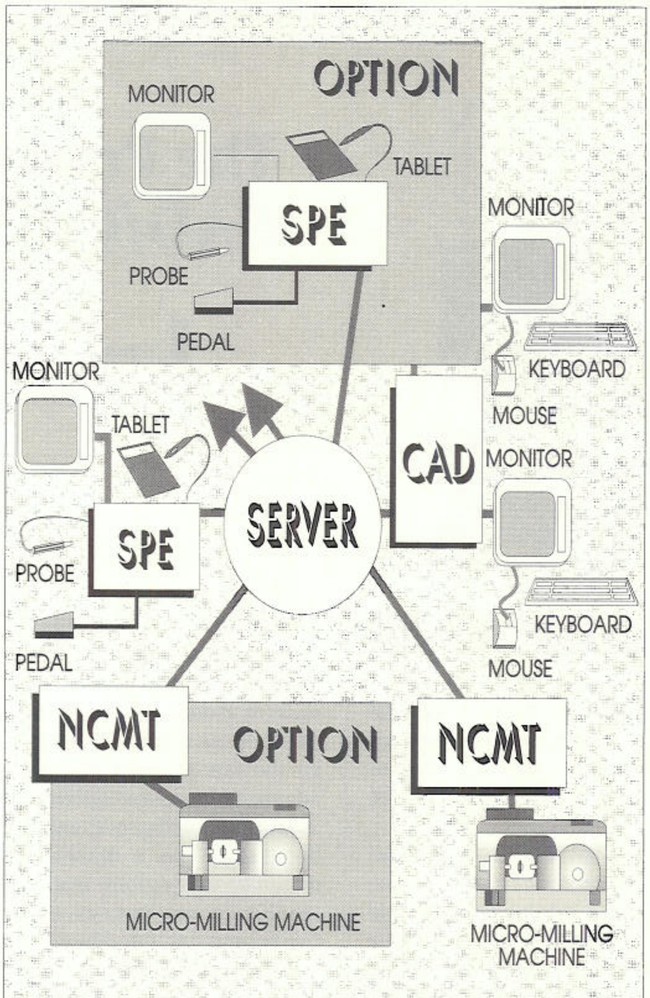

Table 1 : Typical configuration of a multi-station CAD/CAM system.

1.2 How CAD/CAM was developed

From the beginning, it was clear that data must be collected and stored either as digits or numbers, because their values are constant. This, logically, led researchers to work with computers. They were also compelled to use this technology because the mouth cannot be defined, at least for the time being, as a series of cubes and spheres, but only as a group of complex surfaces (said to be warped because of their tormented and irregular features). This makes imaging and shaping them in one plane, i.e. their modification or reproduction with just pen and paper, an impossibility.[11]

It was also quickly understood that practitioners needed the computer to do more than find and record numbers, they also needed it to "perform" dentistry. This is the principle behind the dental CAD/CAM. From a simple device to make copies of the mouth, CAD/CAM's originator's have developed systems that can – in a very short time – make impressions, models, crowns, and bridges, etc.[12] These systems can create images of new non-existing surfaces – basal and lateral surfaces of inlays, lateral surfaces of crowns, etc. – in a patient's mouth, which correspond exactly to the therapeutic wishes of the practitioner.

1.3 How These Technical Results Were Achieved

Today, five models of the dental CAD/CAM are on the market and four others will be introduced during the next five years. This, in itself, is a major technological breakthrough.

However, not all the models available today have the same degree of sophistication. Some are rather primitive, while others are more advanced. Taking these systems in a geological cross-section, it is possible to see all the strata in computer technology and the evolution of the dental CAD/CAM.

Each of these systems has the same purpose, namely to reduce the number of steps required to complete specific dental procedures. For example, minimizing the data transfers from paste to plaster, from plaster to cylinder, etc., CAD/CAM means manufacturing the prosthesis directly with the data taken from the patient's mouth and, at the utmost, it means staying analogical. In short, it is proceeding directly from paste to crown.

The most typical example of a CAD/CAM system in the non-dental world is copying a drawing or sculpture with a pantograph. It is more or less what the CAD/CAM "baby," the Celay system from Nickroma, offers.[16] This system, the last to appear on the dental market, is also the most simple.

It is undoubtedly because titanium is hard to work with that led Andersson[17] and Nobelpharma to develop a system (Procera) that only reams the exterior of the prosthesis, as opposed to manufacturing it directly with the end of a pantographic arm. In this case, the interior is copied in graphite carbon, a material that is soft and conductive. The carbon copy is then placed in an electro-eroding machine to insure a precise manufacturing of the interior of the titanium coping. The Procera system takes the process one step further, by moving CAD/CAM closer to a pure measuring (impression taking) and manufacturing process.

A more advanced CAD/CAM system, as imagined by other researchers, would link a computer directly with the pantograph and the milling unit. Many researchers have worked toward this goal since Mushabac[18] first wanted to use the technique (particularly the Tavor (Switzerland) and Rekow (USA) teams). The principle is this: if the pantographic arm is moved 5.0 mm to the left, we measure 5.0. A calculation unit is placed between the copying and the manufacturing unit to measure each move and identify the position of all the points the operator wants to record. The DCS Titan[19] and DentiCAD[2] systems, which originated from Mushabac's efforts, introduced digitization in primary pantography. However, even with an exceptionally able team operating them, these systems don't approach the ideal CAD/CAM concept. There are still many technical problems that remain to be resolved.[19]

Measuring, in itself, takes away a certain amount of energy from the body or object being measured, which reduces the true value of the data collected. The more a system is invasive, i.e. the more its action is aggressive, the more significant this taking away of energy becomes. And the more this variation of energy is significant, the more the object is likely to vary in its mensuration (a modification of energy almost always produces a volumetric distortion).

In short, to get to the extreme limits of precision, one must get to the extreme limits of respect for the object being measured (which in itself forms a contradiction). And that is exactly the forgotten principle behind optical impression or CAD/CAM in dentistry: it is today the least aggressive method of collecting data to describe the shape of an object. This explains our technological choice, and the development of the optical wave CAD/CAM.

With this type of CAD/CAM, the optical waves hardly "touch" the object being measured – the quantity of energy taken away is so low that it can be said the impression-taking or measuring has not modified it at all (this would be false on a quantum scale).

Two systems have opted for the optical instead of the pantographic solution. The first and most sophisticated, developed by the author, is the Sopha CAD/CAM.[21] The second one, the Cerec system, is more simple, and was designed by Moermann and Brandestini.[13-15]

These systems, which have no middle mechanism, are closer to the pure theory. With optical capture, it is possible to digitize the impression immediately and, therefore, to use the computer almost right away. From the more simple Cerec system, which reproduces the cavity of the preparation in order to make a ceramic piece with no occlusal surfaces, to the more complex Sopha CAD/CAM, which goes as far as to suggest an occlusion model (gnathological or functional), nothing seems impossible using these systems.

Every research team working on CAD/CAM has dreamed of making impressions using optics. The literature has made this abundantly clear. Where two teams have succeeded, to date, many have failed.[3] Impression taking with undulatory means will undoubtedly supplant all other methods in the near future, even if our training still pushes us toward mechanical systems that recall the articulators.

2. The Systems

As can be gathered from the dental literature, a certain number of CAD/CAM systems are available, or soon will be. The intent, here, is not to choose the best available system, or even to rank them in order of preference. (This would be unethical, since the author is a consultant for the Sopha team).

2.1 The Celay System

The Celay system was never intended to be a CAD/CAM system, but it is decidedly geared toward robotization. It was designed by Eidenbenz[22] of the Zurich Dental School, where it has been tested and refined for more than two years. Introduced to dentists for the first time at the 1990 Munich Exhibition, it is now produced and distributed by a Swiss firm, Mikroma.[23]

It has two units, one that palpates the piece to read all of its surfaces and another that manufactures it in a ceramic block by following the manual movement of the sensor by means of a pantographic arm at eight degrees of freedom.

This system makes inlays and onlays with their occlusal surfaces.

Handling

The practitioner first makes a model of the inlay he wants to produce. This kind of direct impression is made from a resin material hard enough to resist the micro-sensor's palpations. It can be taken directly in the mouth or from a model.

After having attached a pre-formed ceramic cylinder of the appropriate size to the machining head (a turbine with lubrication), the practitioner sets the resin transfer inlay (or pro-inlay) under the micro-sensor's arm.

He then follows the surfaces and contours of the transfer inlay in order to transmit, with the pantographic arm, an identical impulse to the turbine's head, which shapes the ceramic in an exact replica of the prosthesis. This is done by hand and takes about 20 minutes.

To complete the piece, the practitioner has only to dress its surfaces.

Personal analysis

Despite the fact that this system has no long-term clinical records, is limited to inlays and onlays, and requires the making of a transfer piece, it has some advantages. For the low cost of approximately $20,000 U.S., it allows practitioners to produce ceramic inlays with occlusal surfaces in just 20 minutes. The training time is fast and the precision of the final product is in the order of 100 µm.

2.2 The Procera System

Designed by Andersson[17] and developed by Nobelpharma, the Procera system is a complex version of the Celay system. It was introduced for the first time in Sweden in 1987, and combines pantographic reproduction with electro-erosion manufacturing. The system is available with a unit that allows the practitioner to solder a titanium bracket between two Procera crowns.

The Procera system produces crowns (for ceramic coating) made of titanium.

Handling

A traditional preparation die is produced and then placed under the reading head of a pantograph, which reads it (circular movement) while guiding the cutting device with a pantographic arm. The cutting device produces two copies of the die, one in a titanium cylinder that will become the crown's extrados and another in a graphite carbon cylinder.

The carbon die is used as an electrode in an electro-erosion apparatus to precisely manufacture the interior of the titanium crown. The procedure is completed by placing ceramic on the crown.

Personal analysis

Three carbon electrodes are generally needed to complete a prosthesis. Many pieces can be produced simultaneously, but the system is relatively slow (the procedure can take two full hours). The system is dependable (both Nobelpharma and Andersson have never lacked imagination). The fact it produces a titanium crown is seen today as an advantage not to be overlooked.

2.3 The DCS Titan System

The results of the work undertaken by Schlegel, Tavor and Zaborsky have produced the DCS Titan or DUX system, which was introduced in Berlin in 1989.[24]

This system can actually digitize data. The DCS Titan collects data with a reading arm and converts it into digital data. This data is then fed into the computer, which ultimately guides the manufacturing unit.

The system comprises a palpation unit that records data from a plaster model, a computer and a numerically-controlled milling machine. It sells for $100,000 to $150,000, and can manufacture titanium crowns and bridge infrastructures in less than an hour.

Handling

After casting the plaster model, the practitioner uses a special micro-sensor to feel the preparation and the adjacent teeth in order to record the surface data on computer.

At the CAD phase, the external and internal contours of the required crown are reproduced in a model. This is used to create a digitized manufacturing program, based on the data that was recorded with regard to the preparation and the crown. (A variation was introduced last year in Cologne that allows the manufacturing of small pontics.)

Manufacturing is performed by a traditional numerically-controlled machine-tool (NCMT), which can produce a titanium infrastructure within an hour.

Personal analysis

This system offers all the advantages of the Procera system, but has a better evolution capability, costs less and is possibly easier to handle (but that remains to be proven). The clinical results show a precision of 100 to 140 µm.[25-26]

2.4 The Cerec System

Invented by W. Moermann and M. Brandestini[13] and developed by Siemens, the Cerec system was introduced for the first time in 1985,[14] i.e. five years after its invention. It is therefore a well-tried system, even if it has not evolved very much.

The Cerec system meets the principles of the optical impression technique. It comprises a camera (approximately 65,000 pixels), an image-processing unit (version 2.0) linked to a viewing screen (of the Macintosh monochrome type) and, since early in 1992, an electrically-driven 2.5 axle micro-milling machine.

This system can be put in the category of the CAM systems. Modelling is done line by line using isoplans, not on surface, to manufacture the internal elements of ceramic inlays, onlays or facets.

Handling

The cavity is prepared according to very precise criteria (margins at 90 degrees from the floor) and without bevel (ceramic inlays);

■ the optical impression is produced in the patient's mouth or on a model after being covered evenly with a white coating to make filming easier;

- depth of field is adjusted, margins are defined and contacts are established on a monitor with a rolling ball;
- a polyhedral ceramic pre-form (Vita or Dentsply) of the size indicated by the computer is installed. Manufacturing takes less than six minutes;
- the occlusal surface in produced and colored by hand in the patient's mouth or on the model.

Personal opinion

With this system, the occlusal surface must be done by hand. This is a disadvantage, since there is a risk of removing too much material. The system costs $55,000 U.S. It has been tried by many dentists throughout the world, is fun to use, rational and simple. The precision of the margins is in the 80-120 μm range.

2.5 The Sopha Dental CAD/CAM System

This French system was invented by the author. It was developed further by many companies before it was taken over by Sopha Bioconcept, a dental branch of Sopha Development, one of the main leaders in medical computer equipment which has had a world reputation in imaging for over 20 years.

Obviously, this system, which took 20 years to be developed, performs the three main functions of a dental CAD/CAM system:

- optical impression-taking (multiviews) with a CCD camera (approximately 250,000 pixels) linked to an image processing system (version 3.1), respectively called the Opticast and the Cubic;
- surface construction and modelling of the future prosthesis, the preparation and the adjacent and antagonist teeth on a polychrome monitor, the BioCAD;
- manufacturing with a numerically-controlled machine-tool, the DMS.

The purpose of this system is to produce anterior and posterior crowns (1989-90), mono- and multi-faced inlays (1992), ceramic infrastructures (1991) and even bridges (1993) under static (1990) and dynamic occlusion (1993).

Handling

Cutting according to the practitioner's methods and the material used;

- impression-taking on model with the Opticast; many views (generally eight) of the preparation and of the adjacent and antagonist teeth;
- definition of the cuspids, fissures, contacts and margins on monitor (method similar to the Cerec);
- automatic or semi-automatic construction (five steps), on these foundations, of the future prosthesis with the CAD program specifically developed for this procedure. If desired, it is possible to modify or control the space for the cement, the crown's shape, its margins and its occlusion;
- automatic manufacturing of the prosthesis in ceramic (1991) or titanium (1992). Fifteen to 60 minutes are required to produce the prosthesis;
- characterization by the operator according to traditional methods.

Personal opinion

Training is simple and is geared toward technicians, assistants and hygienists. A few days are sufficient and no former computer training is needed.

This system is the second one that has undergone enough clinical testing (over 30 units sold to date) to identify its limits and possibilities. The University of South Carolina has used a unit for almost four years now, and it has shown a margin precision ranging from 0 to 60 μm.

The Sopha Dental system is extremely evolutionary and, because it has a central working unit, it opens the door to new possibilities. Both diagnosis and treatment software can be added to this system.

Sopha has launched a new generation of systems that are designed more for laboratories or practice-integrated laboratories, and can produce pieces completely in ceramic (Empress by Voclar or Dicor MGC by Dentsply) for inlays, onlays, crowns and infrastructures. Unfortunately, it has dropped the composite structures, which may have been a mistake.

Working in the patient's mouth is still difficult, and the cost of the three components needed to perform this work is high ($170,000 U.S.). To counteract this problem, Sopha Dental has suggested that the work done in the mouth with the system be temporarily stopped. It has developed an automated camera system to make this possible.

Naturally, as the developer of the Sopha system, the author's opinion of it may be somewhat subjective.

2.6 The Systems Being Developed

Four systems are presently being developed:

The Japanese system: Under the supervision of Professor Tsutsumy, this system has the three usual CAD/CAM components, i.e. the camera, the CAD and the NCMT. The system is only at the development stage, but its inventor, Dr. Fujita, has already produced some crowns with it.[27-29] No clinical experience has been reported to date.

The Cicero system: This system uses the principles of the Sopha CAD/CAM system, but instead of manufacturing the interior of the crown, it produces a special die according to the data recorded by a laser-driven optical sensor that moves along the margins. This special die is then covered with a coat of metal followed by coats of ceramic.[30] This procedure is presently done by hand. When it is completed, the system uses a NCMT to manufacture the exterior of the crown. No clinical experience has been reported to date.

The DentiCAD system: This system is better known as the Rekow system. Since it has been extensively covered in a recent article,[3] we will just refer to it briefly, here. No clinical experience has been reported to date on the work done with the Bego probe.

The Dens system: Developed by Rohleder and Kammer in Berlin,[31] this system is still in its early stages of development. However, a prototype was introduced in Cologne this year. It comprises an optical sensor that is very fast and a NCMT that can work titanium and was developed to this end. It has no CAD yet. No clinical experience has been reported to date.

2.7 The Krupp System

This system deserves to be mentioned because it falls between the traditional method and the robot.[32] Made with a special wax, the prosthesis is used to mould special electrodes that will reproduce the external and internal surfaces, separated at the line of the most important contours. The two moulded electrodes are used, as with the Procera system, to process by electro-erosion non- and semi-precious metals of the Dentitan or Endocast type. It is possible to produce all-metal pieces like crowns and bridges using this system. No clinical experience has been reported to date, but the precision recognized by all who tried it is in the order of 40 µm.

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