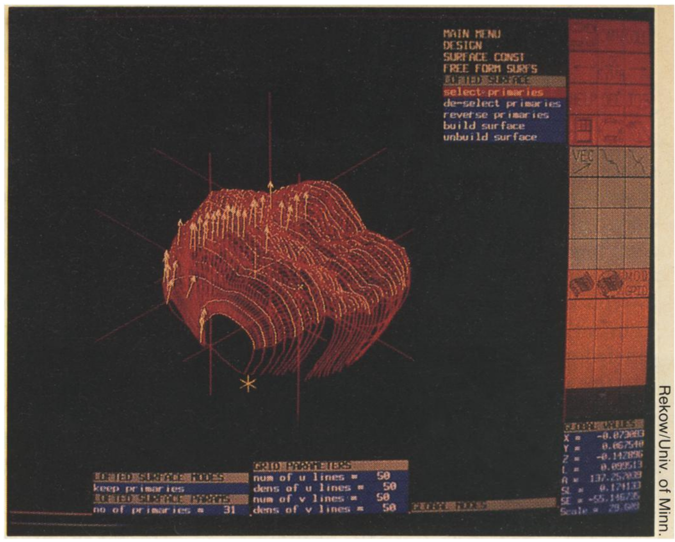
High-Tech Tooth Repair



Rekow/Univ. of Minn.

This three-dimensional computer image of a dental crown was designed in part with the "palette" of design options on the right side of the screen.

Incisive software may allow dentists to stop worrying about making a good impression

By RICK WEISS

Dental researchers are planning a computer-driven revolution that they say could prove both pleasing for patients and profitable for the profession.

To date, the computer's role in the art of dental reconstruction has been largely limited to printing patients' bills and keeping track of their payments. With the advent of small, extremely powerful processors, however, a computer can get directly involved in patients' mouths as a designer and creator of dental prosthetics — a prospect that is spurring both enthusiasm and controversy among dental professionals.

The application of computer-aided design and computer-aided manufacturing — or CAD/CAM — to dental prosthetics foreshadows a revolution in dentistry, researchers say. With its space-age hardware and sophisticated computer graphics, the new technology promises shorter, fewer and more pleasant office visits and an unprecedented flexibility in the types of materials used to make dental crowns, bridges and tooth-surface inlays.

While the Food and Drug Administration (FDA) has yet to approve the technology for use in the United States, a few European dentists already operate prototype dental CAD/CAM systems in their offices. These dentists can fit patients with custom-designed crowns in a single, one-hour office visit. The technique eliminates the need to make time-consuming, putty-like impressions of a patient's mouth, and so could change the dental laboratory's role in reconstructive surgery.

"The use of CAD/CAM for producing dental restoration represents the most sophisticated use of computers in dentistry so far," says Jack D. Preston of the

Henson Int'l

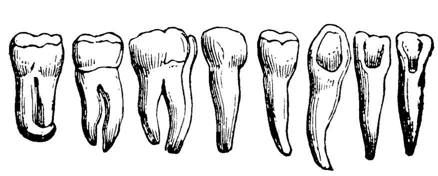
Computer image of a tooth base prepared for capping with a crown. Dentists can electronically highlight the image, generated with the help of an optical "probe" in the patient's mouth, to mark the preferred location of dental margins.

University of Southern California (USC) School of Dentistry in Los Angeles, where a dental CAD/CAM system of French design is due to arrive in February for experimental use. Before long, software-designed prosthetics will become such an integral part of the profession that dental students will "grow up with [computers] like they grow up with the burr," Preston says.

For all the excitement over high-tech dental design, however, nettlesome problems persist. And the sparkling white promises of a new dawn in dentistry have reawakened an age-old dispute in the profession: What level of perfection is acceptable in oral reconstruction?

"Dentistry today is largely an art, and there is very little scientific rigor behind anything," says Reggie J. Caudill, a mechanical engineer at the University of Alabama in Tuscaloosa, who investigates dental applications of robotics and computer graphics. For decades, dentists have argued over exactly what constitutes a suitably snug dental prosthetic. The emergence of computerized engineering — with its emphasis on high-precision specifications, or "specs" — is forcing the profession to crunch some of its numbers anew.

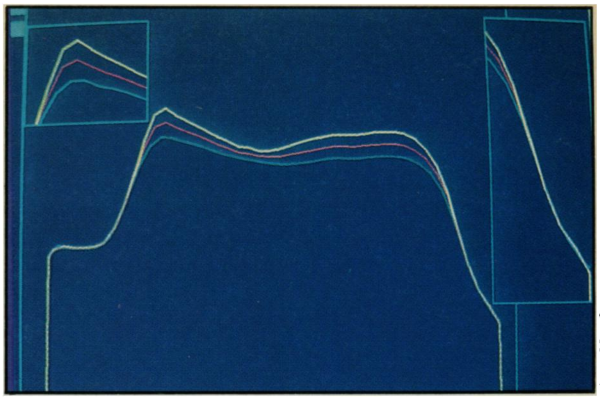
Indeed, says Caudill, "probably what is going to be the biggest impact of all this technology on the field of dentistry is to move it from a qualitative, art-oriented profession to one that is based upon numerical rigor with some real definitions of what is a good fit."



The fundamental technique for making

dental bridges and crowns — permanent replacements for missing or damaged teeth — has changed very little over hundreds of years. This "lost wax-casting" technique today takes at least two visits to the dentist's office, both generally requiring local anesthesia.

During the first visit, the dentist uses a burr (less accurately called a "drill") to grind down the outer layers of one or more teeth, leaving a reduced base upon which the permanent prosthetic will rest. After making a mold of that reduced surface with a putty-like, or "elastomeric," material — a process prone to error — the dentist fits the patient with one or more plastic or stainless steel temporary "caps." The patient wears these for about a week while dental laboratory technicians use the rubbery mold to cast a permanent replacement tooth from porcelain or metal.



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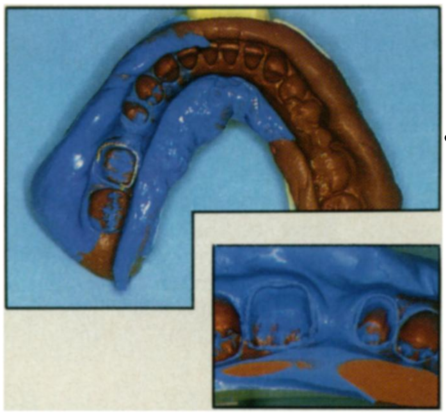
A dentist can use this optical-probe-generated, cross-sectional view of a prepared tooth base (shown in blue) to design the inside surface of a dental crown. Ideally, there should be room for cement between most parts of the tooth base and crown, except around the bottom edges, or margins, where there should be virtually no gap at all. In this view, which includes two closeups of margins, the computer offers two possible fits (yellow, red).



Kerr Manufacturing Co.

The conventional technique for making dental prosthetics uses a putty-like impression material, such as this polyvinylsiloxane compound, as a first step in casting a porcelain or metal replacement tooth.

On the second visit, after removing the caps, the dentist cements the cast crown or bridge permanently into place.

"Anyone who is working in dental CAD/CAM is basically working on the same philosophy: You want to automate making crowns," says Dianne Rekow, a CAD/CAM developer at the University of Minnesota School of Dentistry in Minneapolis. "The turnaround time can be much faster, you don't have to have a temporary, you don't have to have a second set of anesthesia, in theory it should fit much better, and you can do it all in one appointment — all of which has a great deal of appeal."

Meeting this challenge with a computer requires an optical probe that can "read," or map, the detailed contours of a patient's prepared tooth base — eliminating the need for impressions and casts of these spaces.

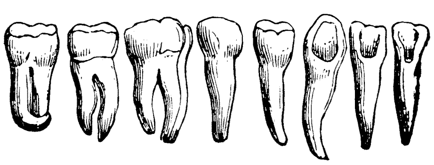
These probes trace the topography of a given tooth surface to generate a three-dimensional computer image. The topographic data are transmitted to a computerized, high-precision milling machine that uses an arsenal of small, rotary cutting tools to carve out the crown.

Rekow heads one of the three leading teams (the others are based in France and Switzerland) pushing to develop dental CAD/CAM systems. "The most critical difference between the various approaches is how the data are acquired — the probe," says Rekow. "And we each think we have the hottest one ever."

The Minnesota system uses a "stereophotogrametric" technique that essentially relies upon black-and-white photographs of tooth surfaces to calculate dental contours. The dental researchers photograph each tooth surface at two different angles. Then a computer, using specially designed software, digitizes the information on a high-resolution array of 4,096 x 4,096 pixels, or data points, from which it can construct a three-dimensional image.

In contrast, the French probe, essentially a bundle of fiber-optic lasers and light receptors linked to a computer, calculates a three-dimensional topographic map from light-diffraction patterns on tooth surfaces. The computer combines three such views to create an image of the entire tooth.

The Swiss system relies on its own version of image generation based on a different means of electronically measuring the intensity of light reflected off tooth surfaces.



The real inner workings of these systems remain closely guarded secrets, and the three teams refuse to discuss details. What's clear is that the French system, developed by dentist Francois Duret with the support of a French company, Hennson International, is closest to market. The Minnesota system, however, while farthest from production, appears to offer the highest resolution and may prove the most accurate. And herein lies the heart of the dental CAD/CAM controversy: Just how accurate is accurate enough?

"A lot of assumptions about acceptable accuracy have been made in the past, and CAD/CAM is putting in question a lot of these assumptions," says Jean-Claude Haas, Los Angeles-based president of U.S. operations for Hennson International. "Dentists have been saying, 'we do this' and 'we do that.' But when you get down to it, it's not quite what they say."

The chewing surface of a replacement tooth can easily be designed from a "library" of images of typical teeth or by flip-flopping the shape of an equivalent tooth from the other side of the mouth. The real trick, though, is to carve the underside of a prosthetic to fit perfectly and snugly over the remaining stump of natural tooth. Especially critical are the so-called margins – the dental edges where crown and tooth-base abut. Imperfect margins may leave a crown or bridge structurally weakened. And a margin gap of more than a few dozen microns can become a focus of bacterial growth, plaque formation and decay.

"It looks like in the laboratory environment, in very tightly controlled conditions, 50 microns would represent the average acceptable accuracy of the margins," Haas says. However, he contends, "there is no way you can reach that level of accuracy in the mouth."

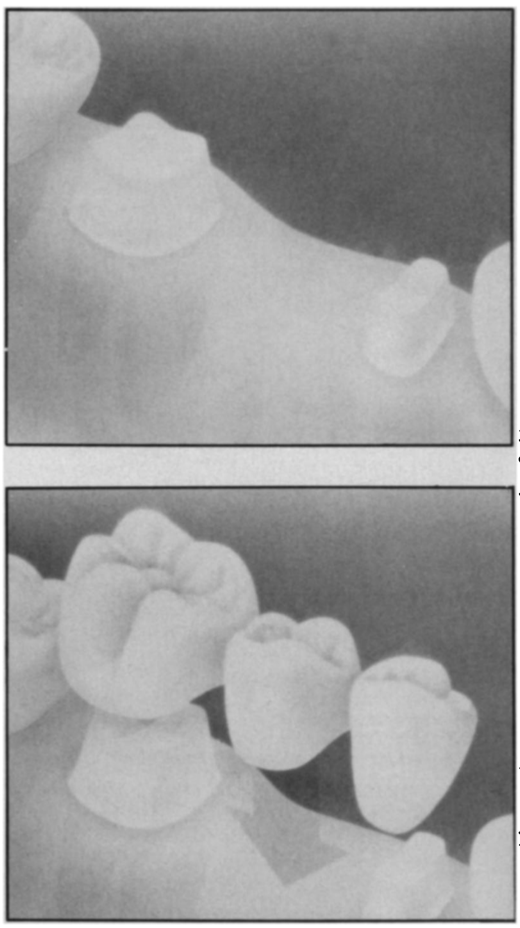
USC's Preston – who disclaims any personal financial stake in the French system about to arrive in his lab but who speaks enthusiastically about its potential – agrees. "In the classic literature the statement is 50 microns, but as I looked back through the literature there is very little basis in fact for clinically making that statement," he says.

At the American Dental Association annual meeting in October, Preston reported margins ranging from zero to 300 microns in patients fitted with CAD/CAM crowns made in France using the Hennson system. The margins averaged 120 microns – a parameter the developers predict will improve with minor changes in software. Haas describes 120 microns as "already somewhat better than conventional methods."

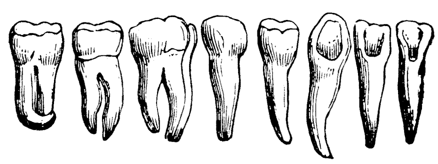
Such margins may be better than many, Minnesota's Rekow agrees, but that doesn't make them acceptable. "I know perfectly well that there are a lot of restorations in people's mouths that are 100 or 150 microns. They're sloppy. They shouldn't be there. They wouldn't pass the boards [required to practice dentistry], and I don't think they should be in people's mouths."

Rekow's design objective, as yet unfulfilled, calls for 20-micron margins – a spec Preston calls "rather difficult to measure, when we get down to the fact that the standard tool used to evaluate margins is 80 microns across the tip."

But in fact, says Rekow, "what you can feel with an explorer is an interesting question. Some of the reports in the literature argue that you can feel 3 microns. Some say it's much higher than that. It's not a clear-cut science."



To replace a missing tooth with a three-unit bridge, a dentist must first prepare the teeth adjacent to the gap, then create a precise, three-dimensional model of these prepared teeth. That model is typically made with a rubbery impression material, but in CAD/CAM systems it takes the form of a computer-generated image. Based on the model's dimensions, a permanent bridge is designed to fit snugly over the prepared teeth. Before CAD/CAM came along, researchers say, dentists were unable to measure accurately the dimensions of a prepared tooth, leaving open the possibility of gaps more than 100 microns wide.

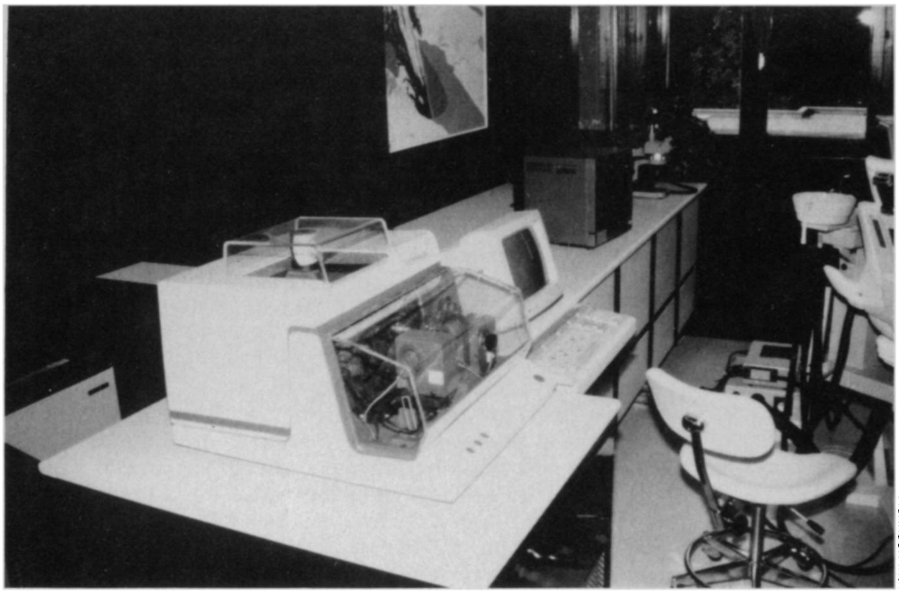


If the science behind dental margins is somewhat marginal, other aspects of dental CAD/CAM are at least less contentious.

"The materials are going to be the most fascinating part," says Henri Rotsaert, who owns a dental laboratory in Hamilton, Ontario, and has "test driven" and critiqued some dental CAD/CAM prototypes.

"A lot of it is still very proprietary – they all have the magic material," he says. But with casting no longer a requirement, "all of a sudden, anything that you can grind, you can use."

That freedom remains theoretical, notes Paul Marinaccio, an engineering consultant to the National Institute of Dental Research in Bethesda, Md. "There's still a lot of work that has to be done just to develop the materials to make this system work," says Marinaccio, who used computers to help design skis, tennis rackets and yachts before moving on to the solid modeling of dental prosthetics.



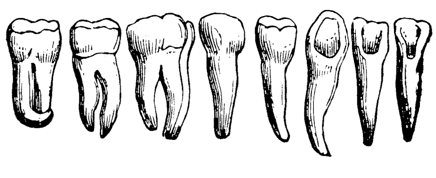
Hennson Int'l

A prototype dental CAD/CAM system fits neatly in a typical dental office. The dentist can make minor changes in bridge or crown design using a desktop-sized computer. The high-precision milling machine (foreground) reads the computer's digital instructions to carve a custom-designed prosthetic while the patient waits.

"People tell me there are machinable ceramics and porcelains," he says. "But it's one thing to say there are machinable materials out there and it's another thing to find a specific material that you can stick in a person's mouth and that is going to fulfill all the necessary requirements. I don't think that material exists yet."

The FDA apparently agrees, so far withholding approval for any new materials proposed by dental researchers. With no equivalent approval required in France, dentists are already fitting some patients with CAD/CAM crowns milled from what Preston calls a "prestructured organic ceramic" made of a "composite resin with oriented fibers" designed to handle the intense stresses of chewing. Beyond that, researchers will not talk about this aspect of the technology.

"Sure, I'll talk about our materials," Rekow says coyly. "They're able to withstand the forces of [chewing], and they're generally nontoxic."



Beyond the remaining technical hurdles, which include improving optical probes, refining graphics software and finding the best-suited milling techniques, there remains the question of cost-effectiveness.

"At first it's going to be mighty expensive, but there's an amazing market size," says Rekow. There are 30 million crowns cast in the United States every year, she says, and dentists pay $70 to $100 in laboratory fees for every crown. "If you could replace most of that, then the cost of the equipment doesn't seem so outrageous."

Researchers estimate equipment costs may run as high as $150,000 at first, making it practical for only the busiest few of the 100,000 U.S. dentists who fit patients with crowns. But as with so many computer products, costs would probably drop quickly after that. And as the computer's capabilities expand to include bridges and inlays – which researchers now are milling but which dentists have yet to fit into patients – cost-effectiveness should increase.

Moreover, CAD/CAM researchers say, individual dentists' costs would be reduced substantially if they chose to install in their offices only the probe and graphical analysis components of the system. Centralized laboratories could handle the milling – as today they handle the casting – by simply going "on line" with dentists' offices. Once a computer digitized all the data describing a patient's requirements, the dentist could send the data by modem to a nearby lab where the milling would be done.

There are bugs to work out in this scenario, notes the University of Alabama's Caudill, who researches dental applications of artificial intelligence. "Imaging systems create a huge amount of data. For one [tooth surface] view, to get the resolutions that we're trying to get, you're talking about 3 to 4 megabytes of data. And then you have to take multiple views in order to get all the information that you're going to need. So you're talking about 10 to 20 megabytes-worth of data," he says. "That would fill an entire hard drive in a personal computer."

Even at today's highest available transmission rates, Caudill concludes, "it would take you an hour or more to transmit the data." To bypass that bottleneck, he and others are developing computer software systems that will choose the most relevant data and disregard the rest before sending it to a lab.

Ideally, he and others say, dental CAD/CAM programs should be "expert systems" smart enough to pick out the most relevant data and present those data to a dentist in an intelligent and interactive manner.

"The system should be smart enough to make the first guess at what that missing part should look like, and it should maintain a knowledge base so as more of these cases are brought to the system, it will actually learn as it goes," says Caudill.

With that capability, adds Rotsaert, when a dentist feeds the computer final plans for a crown, "then the computer can throw it back to you and say, 'Stupid, you didn't take enough off!' So the computer can help the dentist to correct mistakes without having to make new impressions."

Along the same lines, says Preston, one of the great advantages of dental CAD/CAM is that even if a dentist were to damage a crown while perfecting the final fit, it wouldn't be necessary to start over from scratch. With CAD/CAM, he says, "there's still a chance to screw it up. The good news is that the computer remembers exactly what it did, and can do it again."

Finally, Preston notes, the technology offers great potential beyond its developers' immediate aims. He anticipates that mapping tooth surfaces with optical probes will prove valuable for a range of office applications, from keeping three-dimensional dental records to planning orthodontic strategies.

Moreover, he says, "I think there's almost endless amounts that can be done with this as an educational tool. Once you get into that kind of computer power and graphic power, its educational potential is just huge."

Rekow agrees the potential is great. But she warns against dentists moving too quickly into clinical trials of a technology she regards as still very experimental.

"It's my opinion that the system should not generate dentistry, but that dentistry should generate this system," she says. "You have an ethical obligation to use the best technology. And if you can cast better than you can machine, then I think you better cast."

For now, the relative precision of the two methods remains in question – and given the variability in individual dentists' techniques, it may forever remain so. For Preston, though, the direction is clear. "I think it's going to be more fun than I've ever had in dentistry," he says. "And I've always thought it was just a fantastic profession." □