Robots, Bionics, and Bioengineered Replacement Parts in Dentistry

Janyce Hamilton

Ever since Dolly the sheep was cloned, things just haven't been the same. Researchers produced glow-in-the-dark rats.[1,2] A man's ear was grown on the back of a mouse (sure it was a polyester-human cartilage cell blend, but what did you expect?).[3] And then last year, a 58-year-old amputee from Tennessee demonstrated the first bionic arm, flailing it about like a real arm — according to *his thoughts*.[4]

The doors have been blown off their hinges in medicine.

But hold on to your rubber gloves, because the era of "SciFi-like dentistry" is dawning. This article summarizes the best innovations in medicodentistry either in the past few years, currently under way, or on the drawing board. This includes robotics, bionics, bioengineered regenerated tissues, and replacement parts.[5] Let's not forget 3-D virtual reality simulators. In addition, the newly bionic armed, Jesse Sullivan, and the inventor of the technology, Todd Kuiken, MD, PhD, agreed to answer some questions about the first bionical limb. And they speculate on what this could mean for a human bionic jaw.

Author / Janyce Hamilton is a freelance writer working out of Naperville, Ill. Her previous articles for the *Journal of the California Dental Association* include "The Link Between Periodontal Disease and Systemic Diseases: State of the Evidence 2005," "Assessing 'Real Science': Poor Studies, Industry Taking Toll," and "Dental Implications of the Human Genome Project."

World's First Bionic Robotic Limb

Dayton, Tenn. — It was 2001, and a freakish electrical storm had blown into town. A transformer had been hit, and Tennessee Electric Company was in response mode. Jesse Sullivan was working that day in his hometown, like he did most days. As an electrical linesman, this fix was his job. As he grabbed a high-tension wire, a flash of lightning lit up the transformer with 7,000 volts.

Everything was white, then blackness. When he awoke, he learned that death had almost taken him. Emergency surgeons had sewn up his shoulders — where both arms had been burned off.

There wasn't a retirement party. He just didn't go back to work.

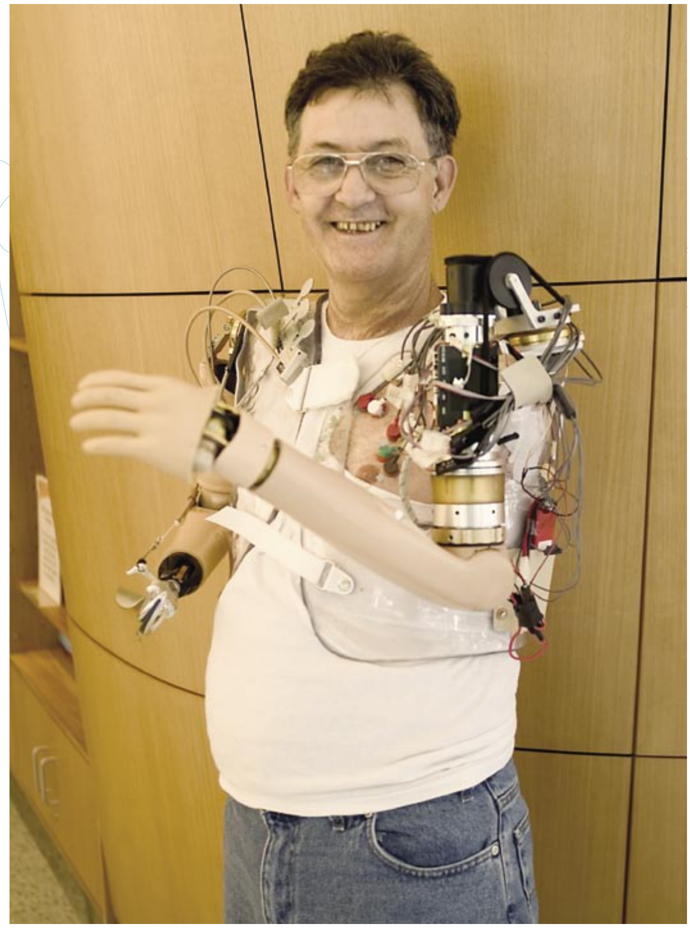
Todd Kuiken, MD, PhD, director of the Neural Engineering Center for Artificial Limbs, Rehabilitation Institute of Chicago, and half a dozen colleagues working together, had wanted to try out his newest nanotech-enabled robotic myeoelectric prosthetic limb. Sullivan, fortunately and unfortunately, was in the right place at the right time.

A surgical team offered him a trade-off. They would give him one traditional hook-and-claw arm. For the other, however, they could attempt something that would make him famous. He agreed. So, they took four nerves ending at his shoulder that would have traveled to his arm, and relocated them in his chest muscles along with electrodes. The nerves grew into the muscle.

"The innovative part for us is regrafting nerves from an amputated limb for the purpose of communicating with a prosthetic limb," Kuiken explained.

Successful surgery thrilled Sullivan, who was only a little let down to eventually learn he couldn't wear the arm at home full time right away. Once when he had been, he broke 12 stainless-steel bolts trying to pull-start his lawnmower. Version 1.0 was not infallible, and it was difficult for researchers to be satisfied, so they continually improved it and asked Sullivan to test-wear it.

The electrodes sense the thought-generated nerve impulses, such as "close hand," and the pectoral muscle contracts, which is carried through the mechanical arm, causing the hand to close. What's more, he can "feel" what his hand does — the first time "a sense of pressure" has been achieved in a prosthesis. Closing his hand feels like squeezing a tennis ball, he reported.



Jesse Sullivan is the recipient of the world's first bionic limb. He can use it to vacuum, carry groceries, eat dinner, take out the trash and put on his socks.

Kuiken and his team have put Sullivan through an obstacle course of duties at the institute to test his bionic arm. He can use it to vacuum, carry groceries, eat dinner, take out the trash, and put on socks. Because of the costs associated (not a discussion point in the interview, but reportedly in the millions), they don't want him putting the arm through its paces just yet. Thus, paused mid-gesture like the horror movie *The Hand*, the arm stays at RIC in the equivalent of a velvet-lined vault. Meanwhile Kuiken tweaks the newest version — the third prototype of the arm.

"Our goal is to have a sturdier, lighter-weight, more cosmetically appealing six-motor arm for him to take home within the next two years," Kuiken said.

He can perform complex tasks like shaving and picking up an egg.

"I throw a ball with my grandson, do laundry, and minor household repair such as painting. I've laid brick with it and I'm also in the process of refinishing my old truck, and the arm has been very useful for that as well," Sullivan said.

Kuiken explained one of the phenomena from moving the sensory nerves from the hand to the skin area of the chest, where his muscles were re-enervated. "By touching a certain spot on Jesse's chest, it feels like you are touching one of the fingers on his amputated hand. The possibilities with this are endless."

Sullivan is the first person in history, the proud director explained, who actually feels how hard he is squeezing with his prosthetic hand. “He can also feel hot and cold in the hand, within a normal range.”

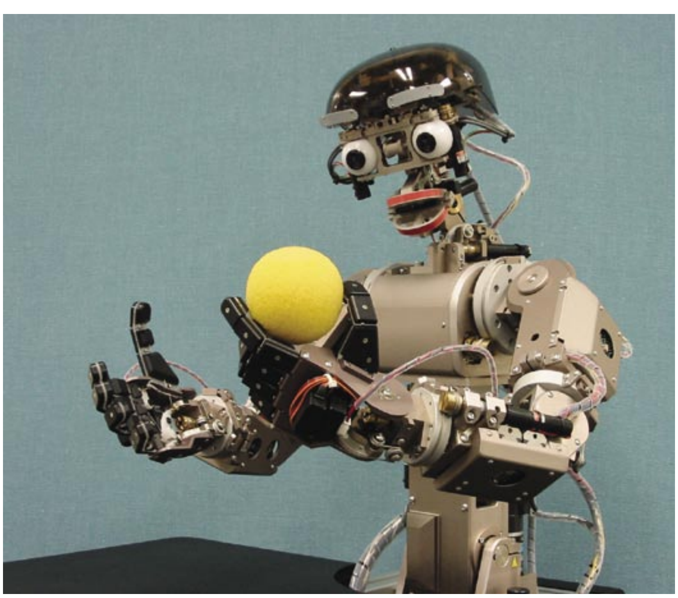
So, a robotic prosthesis (nearly 2 pounds of aluminum, carbon fiber, a 64-bit microprocessor, 14.8-volt lithium-ion battery, motor and gearbox), with its dog sniffing-like electrodes implanted in the chest, now “hears” the brain’s command and triggers the muscle to move the former arm to pick up a glass of orange juice. Perhaps this is the bionic invention of the century. But, the century is young …

Is the Bionic Jaw Inevitable?

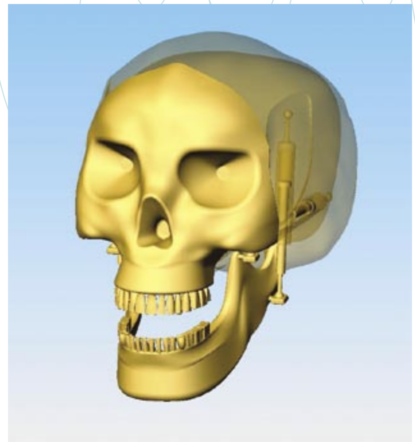
When asked about the possibility of a bionic jaw similar to the bionic arm, Kuiken didn’t wish to comment. He hadn’t thought about it. But Sullivan said he thinks the opportunities with science and robotics seem endless. He added that he hoped his bionic arm would inspire research into every type of replacement surgery, “I genuinely hope this research helps others achieve a level of independence they may not have access to today.”

That includes chewing gum *and* blowing bubbles.

What’s to stop researchers from designing, creating and testing a different nanotechnological robotic feat — an enervated bionic jaw? It’s only a matter of time. The only question is will it be *all* robotic (enervated but removable) or a surgically implanted — permanent and fixed — hybrid jaw: a fusion of human-synthetic parts?



The Infanoid is a lifelike child robot developed in Japan to study communications of young children.



This prototype illustration is of a robotic jaw design with human chewing trajectories that will debut in 2006. *Photo courtesy of Dr. John Bronlund, Institute of Technology and Engineering, Massey University, New Zealand.*

If it’s the former, perhaps it will look something like the robotic human jaws already worked up for evaluating food texture, teeth presence vs. absence, and a tooth shape’s impact on masticatory efficiency.

Drs. John Bronlund and Peter Xu at the Institute of Engineering and Technology, Massey University in Palmerston North, New Zealand, subcontracted by the University of Auckland, mathematically modeled muscles of the human face to mimic jaw movements through muscle contraction in a device debuting in 2006.[6] Said Bronlund, “The device can follow human chewing trajectories exactly.” The effect, perhaps, would look a little like a Halloween skull chewing stale Laffy Taffy.

As for looking toward implanting robotic systems into human jaws, Bronlund said he thinks this is far away. Configuring and coordinating the actuators for delivering the speed, acceleration, force application within the physical dimensions imposed by the human face is a wily task. So far, only the University of British Columbia researchers have made a fully functional, realistically sized jaw capable of movement for speech therapy study, according to Bronlund, but it lacks the forces required for food mastication.[7]

Meanwhile, Japan’s tech inventors at one of its more advanced telecommunications corporations eye these robotic jaw prototypes. They hope to make a hybrid for their Infanoid — a 3-year-old child-like manikin with expressive eyes, lips, and hands used to study communications of young children.

Both nightmarish and fantastical is the imagination of what an expressive lifelike child robot would do or say. (“No” is certainly one of the first words it uttered.)

A 56-year-old man who lost most of his mandible to cancer surgery is the first person to have his own mandible regenerated. It grew on his back. *Reprinted from the Lancet, Vol 364, Warnke et al, Reconstruction of human mandible by tissue engineering, Pages 735-70, Copyright 2004, with permission from Elsevier.*

Those with congenital or acquired diseases paralyzing or necessitating partial removal of the jaw, or who suffer maiming attacks or accidents, some self-inflicted, are lining up for such surgery. One man who did had not eaten solids for nine years because surgeons had hacked away at his mandibular cancer to keep it from eating up his head. And at age 56, he got a once-in-a-lifetime proposal: Would you be willing to be the host site for us to attempt to grow you a second mandible?

Soon a surgical team from the Department of Oral and Maxillofacial Surgery at the University of Kiel in Germany, headed by Patrick H. Warnke, MD, DMD, began to employ techniques, some already tested, but in regrowing an exact duplicate of the man's missing jawbone — *on his back*. So they did.

3-D CT and computer-aided design techniques were used to create an exact replica model of what his healthy jaw would look like, a boon in the planning portion of this pioneering surgical feat. And a simple titanium mesh cage, like a terra-cotta container, was filled with the "human potting soil" of bone mineral, morphogenetic protein and the patient's own marrow. Next, it was implanted into the latissimus dorsi muscle. Seven weeks later, X-rays indicated the jaw was ready. Surgeons removed and delicately transplanted it into the remnants of what once was the patient's lower jaw. Four weeks later, the patient ate bread and sausages: foods that just weren't the same in pureed form.[8]

In 1999, a team from the University of California, Los Angeles, "transferred a totally prefabricated mandible and lower lip and integrated implants subsequently in the mandible," according to the lead researcher, Jay Orringer, MD.[9] It did not, however, involve regrowing the mandible. For that surgery, bone was harvested from the iliac crest. The defects from borrowing bone can extend healing time, part of the reason regenerating tissues has such appeal.

And if a patient's retained teeth and salivary glands aren't fully intact and functioning, these details will be managed in the future, for research teams are working on both. For example, Harold Slavkin, DDS, former director of the National Institute of Dental and Craniofacial Research and current dean of the University of Southern California School of Dentistry, sees only finer refinements to "biomimetics," the design and fabrication of structures and functions based upon biological knowledge to regenerated cells, tissues and organs such as teeth, bones, muscles, and nerves. Teams have been working on the planning of cross-disciplinary projects for, or directly upon, regenerating teeth at California dental schools, Harvard-affiliated medical centers, and around the world although no one would return a call inquiring about the progress on this front.[10] An interesting theory to emerge from the "tooth seed" experiments is there appears to be dental stem cells, which aren't wholly free of controversy.[11] As in the years when the anti-vivisection debate was on the front burner, so today it isn't in a researcher's best interest to draw unwanted attention by providing a quote to any media outlet about fetal, cord, or adult stem cell projects.

Bruce Baum, DMD, PhD, chief, Gene Transfer Section of NIDCR, Bethesda, Md., works with a team on gene transfer and biotissue engineering of an artificial saliva gland prototype.

"Our gland is a small, test-tube shape lined with cells," he said.

Baum didn't think the gland would apply to a bionic jaw prototype, which he speculated could utilize existing functioning salivary glands, should one be designed. Rather, his artificial salivary gland would replace destroyed glands or be used for minimally functional saliva-producing individuals.

"It's been eight years now, but almost everything has been done but implantation in a human. We keep getting closer," said Baum.

Scientists may be wondering what happened to the $3 billion that voters approved by ballot measures in late 2004, via the California Stem Cell Institute Initiative. At some point in 2005, millions of dollars in research support for fetal and adult stem cell biology (not to mention applications for tissue and organ regeneration) were slated for distribution, according to Slavkin. But as of November 2005, two lawsuits reportedly supported by pro-life organizations were filed, forcing the state to halt disbursing the dollars to researchers.[12] No matter how long it takes to untangle this ball of litigation, and whatever the outcome in the state, science will move forward, here, elsewhere in the country or abroad.

One gets the feeling of science as a child who had tossed her tiny snowball down from peak of the Swiss Alps.

In our lifetime, the world will probably see human parts conking out well before their owners, only to be swapped out by a motorized plastic pump, a cloned one from one's cells grown in a swine, or a combination of, or variation on both. Like an alarm clock, the next heart might have NiCad battery backup. Or with a port if one's on battery power and it's losing juice; it's time for a break. Enjoy a green tea smoothie while plugged into A/C for a recharge. The author is reminded of a bumper sticker thought up on her last birthday while registering at the Driver's License Bureau to donate body parts, "Live Forever: Be an Organ Donor to an Organ Donor."

Health care professions are pulling into the Land of Bots, and one guess who'll be doing the surgeries. C3PO, can you lend me a hand?

Robotic Surgery Performed Across the Ocean

Perhaps one has heard of the Zeus Surgical System by Computer Motion. It performed the famed "Operation Lindbergh" to removal a gall bladder from a 68-year-old female patient in Strasbourg, France, while the surgeon operated from Mt. Sinai Hospital in New York in 2001. The patient left the hospital after the usual 48-hour stay.

In February of 2003, telerobotic-assisted surgery was conducted between two distant hospitals in Ontario, Canada. At one, a doctor manipulated the equivalent to what used to be known in the video gaming world as "joysticks" on control panels; at the other, the second doctor supervised the robot surgical system carrying out the other's commands during a live operation on a sedated patient.

Since then, Intuitive Surgical acquired Computer Motion, and has introduced the da Vinci Surgical System. In 2004, an estimated 20,000 surgeries were performed using this robotic system.[13] The system's robots "scale, filter and seamlessly translate the surgeon's hand movements into more precise movements of the EndoWrist instruments" according to company's website. What's more, the console master control is operated by the surgeon; it controls not one but four robotic arms. One may be able to pass the scalpel to yourself while suturing with the other hand, holding a camera to record the operation with the third, and using the fourth to feed the surgeon an egg salad sandwich. Even surgeons with Parkinson's disease and multiple sclerosis should be able to practice longer by having a precise, steady robotic hand doing the work. The 3-D stereoscopic viewer means surgeons feel immersed in the patient's anatomy and pathology.

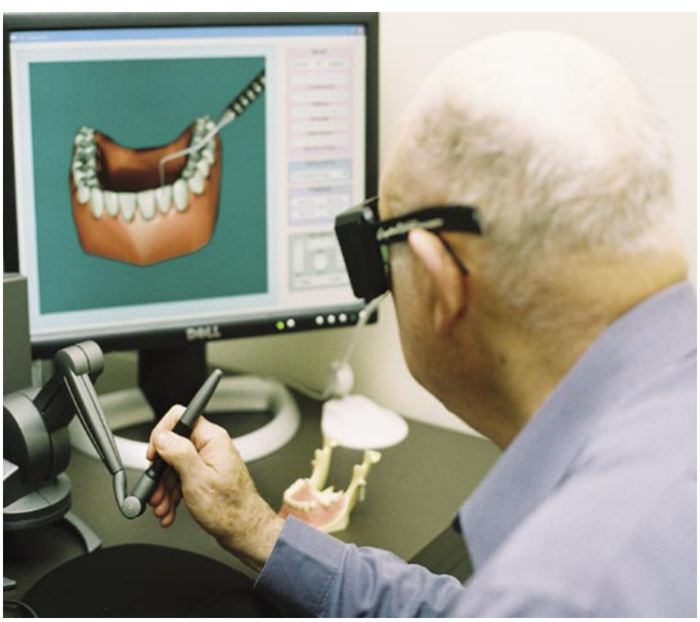
The da Vinci Surgical System is a robotic platform that consists of a surgeon's console, a patient-side cart with four interactive robotic arms, a high-performance vision system and EndoWrist instruments. *Photo Copyright 2006 Intuitive Surgical, Inc.*

At the University of Southern California, da Vinci has been used in the Department of Cardio-Thoracic Surgery in the med school.

"The image of robots doing our work for us like cleaning our carpets is envisioning big robots. The robotics in medicine and oral surgery are ultra-mini devices, some smaller than we perceive with the human eyes, nanorobots," said Slavkin.

Da Vinci-type technology has many potential military applications. For example, one day, maybe the Army, which could use this telesurgery by surgical experts over the Internet to the battlefield, could save solders' lives without endangering the surgeon.

When it comes to craniofacial emergencies, especially for wounded soldiers overseas, Stephen Rouse, a retired military dentist and senior medical engineer at the Walter Reed Army Medical Center, Washington, D.C., uses a 3-D-enabled system. If projectile debris from a roadside explosive puts a hole in a person's head, the correct fit of a replacement "implant" of the missing skull is most important. While the soldier is attended to by medics, Rouse, and Dr. Erge Edgu-Fry get to work. In a few hours, they use CT, MRI, photographic images of the patient pre-injury and modeling software (Freeform Modeling Plus, SensAble Technologies, Woburn, Mass.), to create a virtual clay patch. Digital sculpting tools carve and smooth. The completed model is used to create a 3-D prototype of epoxy resin, which a lab then makes into a implant as if it were another set of rush-job dentures. Overnight delivery to the hospital or hand carried, the patient has something much better than the old-style metal plates. Why stop at robotic *surgery*; how about robotics and 3-D oral cavities for *teaching*?



The Dental Simulator looks three-dimensional when a dental student wears 3-D goggles. The probe on the screen moves where the student moves the virtual reality scaler, as Dr. Arnold Steinberg demonstrates.

Robotic Handpiece Simulators and 3-D Virtual Reality in Education

Dental students are just starting to be trained using prototype robotic handpieces to feel and manipulate 3-D virtual reality teeth in upper and lower dental arches seen on a computer monitor. But how did we get here?

As in private practice, staffing is one of the most costly resources for universities. Salaries have not increased in dental schools as much as they have in the private sector in the past few decades. Not surprisingly, staffing dental departments becomes more and more challenging. As an outgrowth of the drying pool of dental school instructors, and to circumvent practicing on patients, an international crop of inventors are making a mad-dash to develop technological ways to markedly diminish teachers' time *and* practice on human patients. Gone are the days of playing back recordings of dry lecturers talking to the camera. Instead, virtual reality teaching simulators are coming soon to a dental school near you. The simulator will consist of a palm-sized robot handpiece and a computer screen.

University-based research teams, closely guarding their versions of this invention, race to debut the ideal simulator application. They hope theirs will be "the one" purchased in bulk by the world's dental schools. Whichever prototype is seized by the swooping talons of industry scouting for the next hot investment, rights will be sold, and researchers may obtain the prized funding to further their research.

One team hoping to land such industry funding is ready to talk about their alpha phase prototype, a collaboration between the College of Engineering and the College of Dentistry at University of Illinois at Chicago.

Far from Silicon Valley, a cold Midwestern rain pelts the University of Illinois-Chicago campus' windows, causing a White Sox banner to sag. Inside the dental clinic, rows of young masked students stiffly prepare patients, moving as if robots themselves. Professor of periodontics Arnold Steinberg, DDS, MS, hastens to reach his workroom. Once at his terminal, he dims the lights, pulls 3-D goggles over his glasses, and peers at human dentition looking so real, its curvy crowns look like they are about to burst through the glass of the screen.

Using a robotic haptic handpiece called Phantom (SensAble Technologies, Woburn, Mass.) that can mimic a probe, explorer or scaler, his invention, PerioSim, probes the tooth and gingiva on the computer screen. Yet, to his hand, the visible con-

The da Vinci Surgical System's EndoWrist instrument tips can rotate like the human wrist, allowing surgery in the closed chest, abdomen or pelvis.

tact *feels* life-like, not screen-simulated. Steinberg and dental collaborators such as James Drummond, a professor in both the dental and the engineering colleges, incorporated a realistic touch and feel to the robot handpiece. Using haptics, a sense of touch, in the robot handpiece, the student using PerioSim can feel the roughness of a calculus deposit below the gumline, for example, and the smoothness on the root after it's scaled off. On first use, the author jumped like she got a static electricity shock. The Phantom handpiece had jerked when the tip of the probe fell into a gum lesion on a molar.

Patients in rehabilitation centers are already benefiting from robotic devices with haptic capabilities. For example, in physical therapy, a person with an atrophied or numb leg can wear a robotic brace device to "feel" the movements of proper walking.

On the research horizon, for weakened jaw muscles, a robot will also be designed to help with physical therapy exercises. Such exercises would be repeatable, progress would be recorded instantly, and tracked from session to session. If a physical therapist controls the physical therapy robot, a benefit is decreased incidence of carpal tunnel, for example, in the booked-solid, but fatigued, physical therapist.

Back at the University of Illinois-Chicago, 30 clinical instructors gladly evaluated the simulator for teaching purposes, more relieved than threatened to know help is on the way. Back-breaking clinical demonstrations, leaning over patients in small groups where it's often hard to see, will be a thing of the past when the haptic-based dental simulators are here. Their verdict thus far?

"They say this is really lifelike, but not unflawed; really promising," Steinberg said. "What we can do is have an instructor go through a procedure, and record, say, a series of 15 moves, in the simulator. And without the instructor present, the student can play it back and follow along. Sight and sounds are great, but now they are holding the haptic stylus and are guided through exactly the same movements. The student will encounter the same tactile feedback felt by the instructor. Their hands actually feel what the instructor demonstrated.

"Dental schools are short on instructors because the pay isn't great, so we need simulators so students can practice to their hearts content."

Even errors can be simulated to teach common mistakes. If a simulator can be programmed to create an emergency situation when an oral surgeon cannot control bleeding after a tooth extraction, it can test whether or not the student knows exactly what to do, and if he or she can respond in a crisis quickly.

Haptic handpieces could one day be installed at every desk in a lecture hall so students could feel what the instructor is doing.

"This technology could even be deployed over the Internet for training purposes anywhere," said Steinberg.

What's next? The moon? The Space Station?

The University of Illinois-Chicago's Milos Zefran, an associate professor of electrical and computer engineering worked closely with Steinberg in getting the simulator developed. The image viewed on the computer monitor can also be deployed as a 3-D, virtual reality–projected image. This is accomplished by projecting a monitor's image onto a partially silvered mirror with the focal point below the mirror surface. The user looks at the image through the mirror and the effect is perceived by the user as hanging in space in front of the user. This allows him or her to interact and feel the surrounding components realistically as if an actual object is present.

Companies such as ReachIn Technologies (Stockholm, Sweden) have programs for 3-D projection of images, much better than holograms as there is no "ghosting."[14] At the Supercomputer Center at University of California San Diego, many students tried the SynthaGram Glasses-Free 3-D monitor (invented by StereoGraphics: San Rafael, Calif.) a few years ago.[15] Eyewear, however, still provides a superior effect. But since Real D of Beverly Hills, Calif., acquired the company in 2005, improvements such as digital monitors have been made. The company's 3-D projection technology underlies the 3-D version of Disney's recently released "Chicken Little." But will this high-profile involvement change medical and dental virtual reality capabilities? "In time" is probably the best answer for now.

Because in medicine everything will be imaging soon, so goes dentistry. Steinberg predicts students won't have to work on artists' graphics of generic teeth, roots, and other oral tissues on the screen. With MRI and CT scans, a graphic will one day be made exactly of the individual to be operated upon, viewed in 3-D. So, a student can soon practice surgery on a simulation of his patient's thin, weakened mandible to try out a surgery plan and drill sizes, before actually doing the implant or tumor surgery and risking a fractured bone or broken tool.

In 2005, a 24-patient study was published on how imaging can speed up treatment. The patient population, with stable outcomes one-year postsurgery, were beneficiaries of a new 3-D implant planning software for CT scan data. Utilizing surgical templates and taking advantage of pre-fabrication, the final denture, bridge or implant can be immediately loaded using Teeth-in-an-Hour (Nobel Biocare AB, Goteborg, Sweden).[16] Yes, for a fee, any toothless person can plop down and walk out in an hour with his permanent prosthesis in place. This may bring in dental phobics who can afford quality care, but stay away knowing they can't handle multiple visits. But it will be a partnership between imaging and robots in dentistry that gets the A-plus in dental schools. Different than simulation for training, robots will probably eventually perform the surgeries in dentistry they now are doing in medicine. Using a robot device, the actual surgery on the patient could be carried out with the computer eliminating any hand tremor that may be present. If human error will be weaned out, precise and perfect microsurgery will result. What's not to like?

We are not quite there yet, but Zefran said most dentists will certainly see the day when part of their job is to supervise robots that will prepare and fill teeth. Also in 2005, a robotic dental drill (Tactile Technologies: Rehovot, Israel) was FDA approved for testing on humans. It clamps onto the jaw, sends scan data on bone structure to a computer that uses CT data to create drill guides, which then are attached to the frame, and the dentists presses a button and the precision drilling commences. Its inventor says this could be "the first step toward more automated dentistry."[17]

Above is a prototype of the 3-D Stereo Display, which responds to pupil commands of the viewer and does not require goggles. The equipment enables clinicians to feel they are immersed in the image. *Photo courtesy of Health Group Technology Innovation, Eastman Kodak, Rochester,*

"It definitely will be possible to get a prosthetic jaw like a prosthetic limb, one day," Zefran speculated.

For Sullivan, the prosthetic robotic arm is connected to a stump. With the jaw, it's more problematic potentially due to the saliva and biocompatibility, and cosmetic issues.

"These are not insurmountable obstacles," said Zefran. "Plug in the device, use it to chew and talk, and take it out to clean it. One has to dream to design, engineer, build and test."

Pupil Commands to Manipulate X-rays

Ever get the feeling that someone was staring at you, turn around, and find someone was staring at you? Now, one can have that unnerving experience of feeling like a machine is staring at you. But this time, it's trying to look you in the eye.

When Carlos Munoz, DDS, MSD, professor and chair, University at Buffalo School of Dental Medicine, Department of Restorative Dentistry, SUNY, Buffalo, visited the Kodak Health Group innovation lab in Rochester, N.Y., he got a surprise. "Technology is moving extremely fast. So fast that you can move an X-ray and enlarge it with your eyes."

Next, Munoz characterized the eye-gaze tracking and 3-D stereo display prototypes, he saw "calibrating the eyes' pupils" and responding to them, along with voice commands, and then seeing the patient image in the 3-D stereo display. The manager of Eastman Kodak's Health Group

Technology Innovation, Steve Russell, talked about the "immersive" system as "autostereoscopic"— no glasses or headgear needed.

But unlike the other companies trying to come up with their own prototypes of glasses-free monitors with 3-D effects, this one uses voice recognition to help command the system to enlarge, reduce, zoom in on a segment of the patient image, enhance an image to see more detail, or mark areas of interest to include in the patient's record. The authorized user will also be able to access other information in the patient's electronic medical record without having to leave the patient's chairside.

Russell described these efforts as part of the company's health care workflow solutions: "The advanced prototypes allow clinicians to experience and navigate images as never before. The viewer feels as if they have been immersed into the image. Three-D stereo displays and other advanced human-computer user interfaces, like eye-gaze tracking and voice recognition, will eventually surpass current technology, reducing the clinicians reading time, improving performance and productivity, and enhancing workflow. "

Limitations

Using minimally invasive procedures for fast healing, miniaturized motors and nanosized technologies is exciting. Replicating and manipulating human body functions is otherworldly. Employing robot arms in the practice of oral craniofacial surgeries and restorations will be better than playing a computer game because it will be the real deal.

But cost-benefit ratio in these advanced areas today is so lopsided, it can be a "guesstimate" for researchers to estimate additional funding that will be needed, even after they've started a robotic or bioengineering project. As a result, once the checks written from the grant account bounce, it's time to take out a personal loan or cross one's fingers for investors.

Fred Eichmiller, DDS, director of the ADA Foundation's Paffenbarger Research Center in Gaithersburg, Md., espoused a pragmatic view: "This is fun, but its population impact benefits are very few and so there won't be taxpayer dollars going into it. In education, robots make sense because there's a shortage of instructors. But when it comes to using CAD-CAM and robots in the dental office, there wasn't a real problem to begin with, so this is like nanotechnology in search of problems."

In dental education, 3-D virtual robotic simulators may be a challenging shift in the role of human educators. But it remains uncertain if universities can come up with the cash to invest in their development or purchase more than a few of them for clinical training.

The cry is "the big companies will pay for it," but not so fast. Handing over millions isn't the way of the big consumer health companies in the 2000s, with their acid-refluxing stockholders instead clutching the comforting promise of steady sales in the next swan-shaped toothbrush head.

If manufacturers analyze the investment and see a guaranteed return, they toss in a line baited with a small pilot project and see if it lands the biggie. Even the average American, who may have amnesia about world and national events, can name the date of "Black Monday." When it comes to their money — no one forgot the tech stock craze that wooed first-time investors and later deflated the tires on their hopes and dreams.

Conclusion

Previously unthinkable innovations, such as spray-on skin cells for burn victims, are the grist of researchers pushing to see how far than can go in medicine.[18]

Meanwhile in the oral craniofacial field, so poorly characterized by the catch-all term "dentistry," bioengineered replacement parts are in the works. Like when a big organic grocery chainstore puts out of business the small grocer in the same strip mall whose buyers didn't know people really do want organic ginger-teriyaki portabella wraps rather than tuna salad hoagies, there's good news and bad news.

The good news is that oral training and care will eventually be improved by robotics, bionics and bioengineered parts. The bad news is it might take some time because these are diamond-studded inventions with platinum parts — the most expensive research the profession has seen yet.

According to a 2005 American Association of Oral and Maxillofacial Surgeons report, emerging technologies are unstoppable and all over the board.[5] For example, "biological glues" for bone welding could one day replace metal fixation.

Finally, for those who think the bionic jaw is highly improbable, a "mandibular growth center" is in the crosshairs of a team of collaborators from the Massachusetts General Hospital's Departments of Oral/ Maxillofacial Surgery and Oral Fabrication and the Tissue Engineering Laboratory. The team is also reportedly already entrenched in engineering a mandibular condyle substitute.[5]

Now, if all the people in this report would just talk to each other during a weekend retreat. Or even just use up their "Free Anytime" minutes. The news headlines would be announcing the first bionic jaw sooner rather than later.

One request, however. Candidates for motorized jaws must be "the quiet type." CDA

References / 1. Wilmut I, Schnieke AE, et al, Viable offspring derived from fetal and adult mammalian cells. *Nature* 385:810-3, 1997.

2. Petit C, Firefly genes light up Stanford research mice. *San Francisco Chronicle* Oct. 11, 1997:A1.

3. Scientists grow 'human' ear on lab mouse. CNN.com. Web posted Oct. 25, 1995.

4. Dyer N, A toast to the bionic man. *Popular Science*, available at: www.popsci.com, Oct. 10, 2005.

5. Troulis MJ, Ward BB, Zuniga JA, Emerging technologies: findings of the 2005 AAOMS research summit. *J Oral Maxillofac Surg* 63:1436-42, 2005

6. The robotic human jaw. Albany, New Zealand: Massey University, Massey News July 28, 2005.

7. Lin B, Unique robotic jaw will advance speech research. Vancouver, B.C.: Canada. *USC Reports* 51:8, 2005.

8. Warnke PH, et al, Reconstruction of human mandible by tissue engineering. *Lancet* 364:735-70, 2004

9. Orringer JS, Jaw restoration procedure questioned. *Cosmetic Surgery Times* Jan. 1, 2005.

10. Harris A, Mammalian teeth regrown in lab. Focus available at http://focus.hms.harvard.edu/ 2002/Sep27_2002/tissue_engineering.html. Accessed Nov. 23, 2005

11. Sharpe PT, Young CS, Test-tube teeth. *Scientific American* August 2005.

12. Varney S, Lawsuits stall California's Stem Cell Initiative. Day-to-Day, NPR Radio Broadcast Nov. 11, 2005.

13. Cropper CM, The robot is in — and ready to operate. *BusinessWeek* March 14, 2005.

14. Welcome to ReachIn Technologies and the world of high fidelity haptics. Available at: http://www.reachin.se Accessed Nov. 23, 2005.

15. Glasses-free 3-D breakthrough scientific visualization: SDSC uses SynthaGram Glasses-Free 3-D monitor from StereoGraphics. Available at: www.stereographics.com/news_about_us/03news/pr102203.htm . Accessed Nov. 23, 2005.

16. van Steenberghe D, Glauser R, et al, A computer tomographic scan-derived customized surgical template and fixed prosthesis for flapless surgery and immediate loading of implants in fully edentulous maxillae: a prospective multicenter study. *Clin Implant Dent Relat Res* 7:Suppl:S111-20, 2005.

17. Knight W, 'Robotic' dental drill to be tested on humans. April 20, 2005. Available at www.newscientist.com/article.ns?id=dn7288 . Accessed Nov. 23, 2005.

18. Gilbert P, Spray-on cells treat severe burns. BBC News World Edition. Sept. 5, 2005. Available at http://news.bbc.co.uk/2/hi/health/4208746.stm. Accessed Nov. 23, 2005.

To request a printed copy of this article, please contact / Janyce Hamilton, 110 Townsend Circle, Napierville, Ill., 60565.