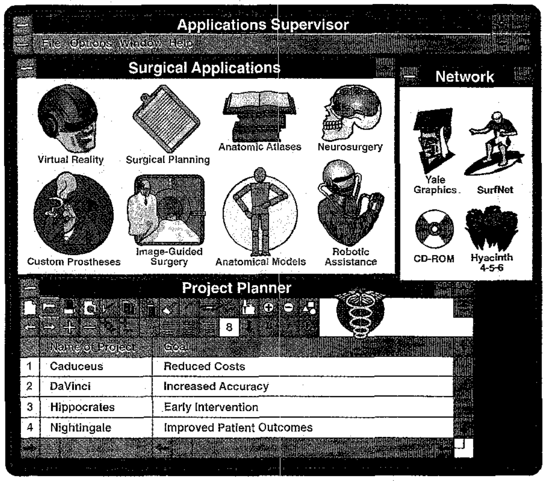

Computers in Surgery and Therapeutic Procedures

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Medical imaging has come a long way since Wilhelm Roentgen discovered X rays and provided the foundation for radiology just 100 years ago. Stunning, in vivo anatomic presentations from computed tomography (CT), magnetic resonance (MR), digital ultrasound, and other forms of computer-assisted diagnostic radiology have captured subtle disease processes never before seen so early in development. Such presentations have helped physicians finally understand complex disorders in a vivid three-dimensional context. But how do these pictures affect the patient's overall quality of care?

Unless doctors respond with the appropriate therapy, expensive diagnostic technology may only add to the national health-care costs being so hotly debated. This is changing. Physicians are actively collaborating with engineers and other colleagues—more than ever—to respond earlier, at less health risk, and with lower cost to disorders that would otherwise become debilitating, personally tragic, and extremely expensive to treat. The cost of medical care is reduced by speeding surgery, increasing its accuracy, and reducing the frequency of subsequent procedures.

This theme issue of *Computer* examines applications of digital imaging in medicine and their integration with surgical procedures. Together with the January issue of *IEEE Computer Graphics and Applications*, this issue introduces exciting, innovative uses of computers in medicine and demonstrates how digital technology is reaching the surgery room.

BACKGROUND

In a broad sense, surgical treatment has been assisted by computer and electronic technology since the 1960s, when patient-monitoring devices were introduced to the operating theater. CT and MR imaging (MRI) modalities increased this integration, allowing computers to be used in the immediate analysis, measurement, and display of medical problems.

CT and MR scanners' imaging capability revolutionized radiology and changed health-care economics in a way that haunts us still. When first introduced in the US, these new, expensive scanners caused an unprecedented shift of health-care payments to diagnostic imaging services. These costs have now receded to a new balance that reflects a more mature market and equipment at lower cost with even more powerful capabilities. These diagnostic tools have also established the foundation for entirely new applications in surgery as their computer and image-rendering resources have been adapted to new software for surgical procedures.

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REQUIREMENTS OF COMPUTERS IN SURGERY

High technology is of little use to clinical medicine unless it simplifies an otherwise complicated procedure, improves patient outcomes, and is less expensive than the alternatives. In times past, meeting two of these requirements might have been sufficient for a successful application. With the current unprecedented scrutiny of health-care costs, all three requirements are necessary for the technology to become practical. It is our obligation as engineers to scrutinize the cost of our technology in medicine; that is, we must review technology with a critical eye in regard to health-care expense. Can our technology help the patient in the waiting room now? Will the capital investment our innovations require be practical for the user group?

The demands placed on technology in medicine are not limited to the economic conditions above. Under all circumstances, the reliability and accuracy of surgical applications must be confirmed and validated. Medical personnel cannot divert their attention to making the computer work. It must be completely reliable and unobtrusive in the operating room.

When these requirements are met, computer applications in surgery can deliver

- efficient surgery, with reduced operating room expense;
- less morbidity;
- procedures with fewer complications;
- increased surgical precision to reduce possible damage to adjacent tissue;
- improved patient outcomes (faster rehabilitation at lower cost, with less interruption); and
- an opportunity to perform new, or previously impossible, minimally invasive procedures.

Finally, medical information can distract and overwhelm, if not presented thoughtfully. Doctors are frequently on the edge of information overload, but computer engineering can repackage the same amount of information more conveniently for them. For example, easy access to multimedia patient records can simplify a diagnosis or help guide a surgical decision. If not easily accessible, or if buried within medical telemetry, such data has no place in the surgical suite.

COMPUTER SUPPORT FOR SURGERY

Digital technology has penetrated nearly every aspect of medicine, as it has every other industry. In surgical procedures, digital instrumentation spans patient monitoring and health-data analysis and the manufacturing of custom anatomic models. Data gathered from CT or MR scans are used to generate skeletal models for planning and practicing reconstructive procedures. These same data are also used to generate custom prostheses that match complex 3D shapes otherwise nearly impossible to create without long, tedious, and possibly dangerous surgery.

CAS APPLICATIONS

Computer-assisted surgery has been implemented in the following areas:

- **Neurosurgery.** Computers have become integral to brain surgeries that use head-fixation devices (stereotactic frames) and other devices that register brain structure using anatomic landmarks to guide access to tumors and other neuropathology. These methods use software and image-registration techniques to reach submillimeter surgical accuracy.
- **Surgical planning.** CT images are processed by object-isolation software to generate life-sized cross-referenced images along and across the mandibular arch in the mouth to plan surgically embedded dentures.
- **Anatomic models.** Computerized numerical control machines and object-forming laser (stereolithography) systems generate models of skeletal defects to plan corrective surgery. These models are life-sized, 3D, hand-held replicas of actual patient body parts.
- **Custom prostheses.** Data from CT scanners are used to create orthopedic implants.
- **Robotic assistance.** A robot has assisted the accurate placement of artificial leg joints in veterinary medicine; similar robotic assistance has helped position biopsy instruments for human brain surgery.
- **Image-guided surgery.** Surgical procedures to repair blood vessels often use X-ray images to help track and guide the course of intravessel instruments. Were it not for the extended exposure of X rays to both patient and physicians, such image-guided procedures would be more commonplace today. This is changing. Low X-ray dose devices, ultrasound, and recent "open" MR scanners that allow real-time access to patients while the images are being generated provide the opportunity to better guide surgical devices during operations.
- **Custom anatomic atlases.** Digital atlases have been created for surgery education to illustrate anatomic differences between individuals. Actual anatomic views can be explored in an unrestricted way, and organ systems can be labeled with adjoining descriptive text.
- **Virtual reality.** This method lets surgeons practice through simulation to optimize actual procedures.

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INTERVENTIONAL RADIOLOGY

This technique covers a broad spectrum of invasive diagnostic and therapeutic procedures. Angiographic procedures provided the precedent for merging diagnostic imaging equipment with interventional procedures. Angiographic procedures let physicians view brain and heart blood vessels after dye has been inserted to illuminate them. However, improved capabilities of ultrasound, fast CT, and new magnet architectures for MR scanners that allow easy access to patients during imaging invite extensions to traditional interventional radiology. Minimally invasive surgery is becoming more common as the serial steps of diagnosis and therapy are beginning to merge into one procedure.

Historically based on X-ray images, ultrasound, CT, and more recently MR, scanners are being used to guide surgical instruments in many new applications. For example, "open" MR scanners offer exciting possibilities for surgical applications. Unlike the more traditional MR scanners that place patients within a tub-like cavern inside a large magnet, open MR scanners provide nearly unrestricted access to patients during the imaging procedure. Since no X rays are used, continuous images can be produced during surgery. These images can be produced rapidly (at screen refresh rates) with exceptional soft-tissue contrast and unlimited orientation.

Interventional MRI is still in its infancy because only a few centers are capable of actively developing it. As with any medical procedures, interventional techniques must be carefully examined by the medical community to validate safety and effectiveness. This examination includes the participation of radiologists, surgeons, engineers, and when necessary, federal regulatory agencies. All of this, plus the availability of new, sometimes exotic equipment, tends to limit such experimental procedures to a few medical facilities. The benefits, however, can be dramatic. For example, real-time MRI can let surgeons monitor hyperthermia therapy by ultracold (cyrosurgical) or hot (ultrasound, laser, or radio-frequency) instruments.

Tracking interventional hardware is now possible. Catheters that have a micro coil at their tip to detect an RF signal can be used to locate its position. Since the catheter's tip position is known, the MR scanner can then acquire one or more images precisely at the location of the tip. This allows the trajectory of biopsy devices to be shown in real time without stereotactic frames. The position of the biopsy tool is constantly illustrated in the context of local anatomic structure and pathology. We can now generate anatomic views for genuine therapeutic procedures that are similar to the imaginary views from Hollywood in the film "Fantastic Voyage."

COMPUTER-AIDED SURGERY INCLUDES a wide range of procedures. New areas such as multimedia surgical support, interventional radiology, and minimally invasive procedures all use digital systems as a basis for these pioneering efforts. ❚

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Companion issue available

The January 1996 *IEEE Computer Graphics and Applications* companion issue to *Computer* on applications in surgery and therapy is available at half price ($10 nonmembers, $5 members). It contains the following articles.

- "Multimodal Image Fusion for Noninvasive Epilepsy Surgery Planning," by Stephen T.C. Wong, Robert C. Knowlton, Randy A. Hawkins, and Kenneth D. Laxer—A neurodiagnostic workstation integrated into a hospital picture archiving and communication system supports low-cost, low-risk epilepsy surgery planning by combining biomedical information from four neuroimaging modalities.
- "NeuroNet: Collaborative Intraoperative Guidance and Control," Robert J. Sclabassi, Donald Krieger, Robert Simon, Ray Lofink, Greg Gross, and Donald M. DeLauder—Neurophysiological monitoring assesses CNS structure-function relationships during surgery. NeuroNet supports remote performance of this task through real-time multimodal data processing and multimedia network communication.
- "Assessing Craniofacial Surgical Simulation," Vikas V. Patel, Michael W. Vannier, Jeffrey L. Marsh, and Lun-Jou Lo—The validity of graphically rendered CT or MR scanned images is carefully measured by simulating craniofacial surgical procedures and testing each step in the process.
- "An Optical 3D Digitizer for Frameless Stereotactic Surgery," Scot A. Tebo, Donald A. Leopold, Donlin M. Long, David W. Kennedy, and S. James Zinreich—This frameless system for defining the precise spatial coordinates of a site of surgical interest has many advantages over conventional frame-based systems and provides accuracy comparable to commonly used units.
- "3D Heart-Vessel Reconstruction from Biplane Angiograms," Andreas Wahle, Helmut Oswald, and Eckart Fleck—Biplane angiography generates just two time-equivalent X-ray images, but highly accurate 3D models of vessel systems can be reconstructed, visualized, and quantitatively evaluated from them.

To order the January 1996 issue of *CG&A*, call (800) 272-6657 or e-mail cs.books@computer.org and mention this special companion issue offer.

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