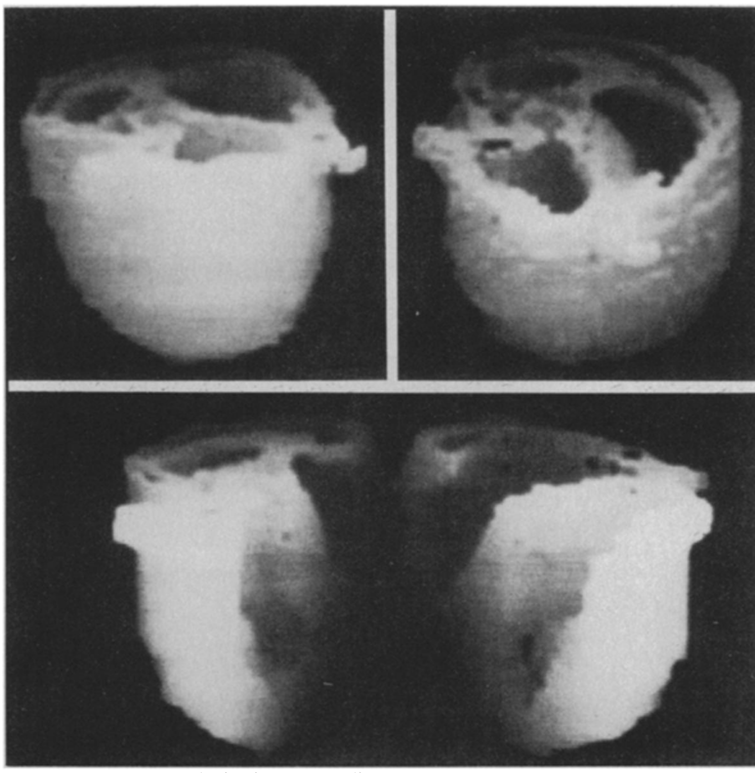
Noninvasive Vivisection

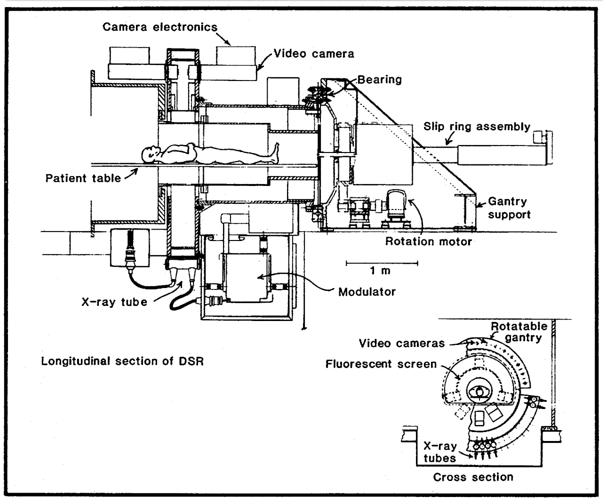
It is now possible to view the interior of the living body without ever touching a scalpel

BY JANET RALOFF



Television views of a living dog's heart, reconstructed by DSR*'s computer from scans by a single X-ray tube.*

Mayo Clinic



DSR *schematic illustrates configuration of the patient assembly and the 13-ton rotating gantry (which will eventually house 28 X-ray tubes). Patient lies across a radiolucent table. A video camera picks up intensified fluorescent images, which are digitized and stored in a video-disk recording system.*

Ritman/Science

Vivisection implies cutting open an animal or human. And "until now, it was the only way you could get direct confirmation of what is going on inside the body," says Erik Ritman, an Australian research physiologist at the Mayo Clinic in Rochester, Minn. But no more. An experimental tool being developed at Mayo dissects the living body — without harming it — using a mathematical knife.

"[T]he beating heart can be selectively removed from the chest and examined electronically. It will be like doing exploratory surgery on an awake patient, painlessly, without altering the patient's physiology," Ritman explains. And that's important, he says, because with traditional surgery, "the moment you open the chest, the lungs collapse and the environment of the heart changes. So even if you make accurate measurements of organs, the information is of doubtful validity, in a physiological sense, because you have changed things."

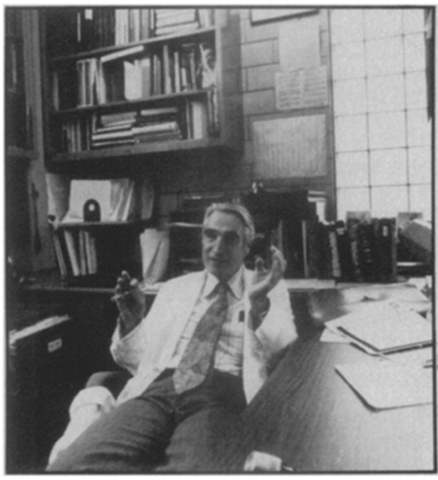
Grandchild of the computed tomography (CT) scanners, Mayo's new imaging system is saddled with the even more imposing name Dynamic Spatial Reconstructor (DSR). However, while both machines are based on similar principles, they operate somewhat differently. Chief among these differences is that CT scanners construct images resembling two-dimensional salami-like slices, while DSR dices the body. Then, electronically, DSR reassembles the cubes to form a moving, three-dimensional life-size X-ray image of the body. And since it stores data on a volume, not just a slice, at the user's discretion the system can be asked to reconstruct slices of the region scanned, at any desired angle, or chunks at any location.

Selected organs, such as the heart, can be singled out on DSR's viewing screen. Then, once isolated, muscle tissue can be electronically dissolved from the image — somewhat analogous to the way pathologists dissolve away tissues with chemicals. One can arrange to view just the arterial tree, for example. If necessary, the heart can be rotated, turned over or opened up to permit viewing of its interior structure. Objects can be enlarged selectively with detailed resolution. And the heart continues beating normally through it all. Movement can be slowed, speeded up, stopped or even reversed for an instant replay.

The heart of the DSR is a battery of X-ray tubes (the machine held 14 at its dedication last month and will house 28 by the time it is fitted to design capacity). Rotating on a 13-ton gantry at a rate of once every four seconds, the X-ray tubes fire in rapid succession; all 28 will pulse within a hundredth of a second and repeat the sequence 60 times a second. In fact, the speed with which it will acquire data is nearly 10,000 times faster than commercial CT-scanners, according to Ritman and colleagues in the Oct. 17 SCIENCE.

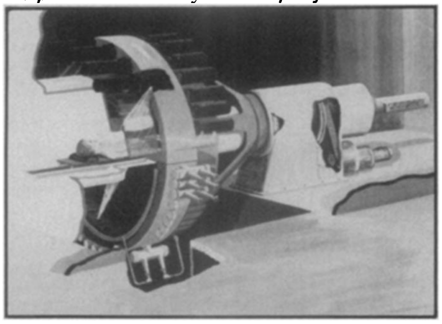
When completed (with all 28 X-ray tubes installed), DSR will be capable of generating 15,000 cross section images per second. Four seconds worth of data — the equivalent of roughly four heart beats — will be stored in computer memory from which 3-D images can be reconstructed in virtually "real" time.

Imaging occurs on a flexible mirror that vibrates rapidly like the head of a drum. Individual cross section images flashed from a cathode-ray tube (TV screen) before it will, when reflected on its surface, meld into a cloud-like "volume" — holographic in appearance, according to a description in the design in the January 1979 MAYO ALUMNUS.



Photos: Mayo Clinic

Earl Wood: One of the researchers who helped launch Mayo's DSR *project.*



Cutaway drawing of X-ray guns mounted on doughnut-shaped gantry. They rotate about patient once every four seconds.

Alternatively, stacked cross sections can be projected onto a television monitor. The resulting image is only two-dimensional. For visual 3-D translation, the Mayo designers have rigged up a system that simultaneously projects two images that represent viewing angles displaced relative to each other at a value corresponding to binocular disparity. When viewed as a stereo pair, full volumetric visualization is restored.

The massive collections of data it stores and processes give the DSR system its viewing-angle and imaging versatility. "[T]he Landsat III earth-resources satellite transmits images to its receiving stations at a rate roughly equivalent to 2.5 million samples per second," say Ritman and colleagues. That's "less than one percent of the rate of DSR data transmission." But figuring out how to process these massive quantities of data in anything approaching real time (virtually the same time it is collected) has given the project's computer scientists headaches.

"Conventional computers reconstructing each cross section within several minutes would require up to 50 days to compute the images that can be reconstructed from a one-second DSR scan," the group claims. "However, the time between the collection of the raw data and the presentation of the final results should be only a few minutes to maintain useful 'feedback' between the observer and the patient or experimental animal under study."

"To achieve this goal," the team explains, "we have designed and are fabricating special-purpose computers" that exploit advanced digital-device technology in which the arithmetic processes are tailored to extract maximum performance from the computer's problem-solving operations. If a reconstructed image is to be shown within a few minutes of the X-ray scanning sequence, even using a computationally efficient reconstruction program, DSR's computer will have to process a minimum of three billion arithmetic operations per second, they say. In part, it's a limit on the ability of DSR's computer to handle all the data they will furnish that holds up installation of the full complement of X-ray tubes. The Mayo team is reasonably certain, however, that these and yet-unforeseen design challenges will be worked out as the current machine and DSR's theoretical design both undergo a two- to three-year intensive shakedown and analysis phase.

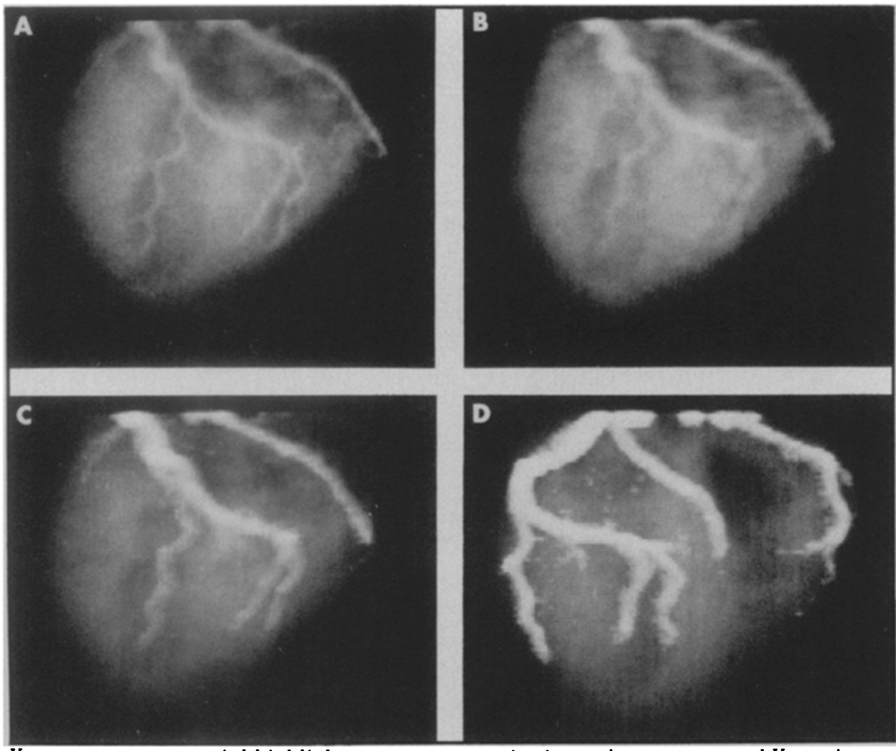
"When we became convinced the DSR would work," recalled Earl Wood, a physiologist who helped launch the Mayo project seven years ago, "we just kept putting in one grant request after another until we were funded." Their persistence paid off. The first scans of a living dog heart were performed early this year.

Based on a range of tests, none as yet conducted on living humans, it appears the DSR system will prove immediately beneficial for research on heart-muscle disorders (such as rheumatic heart), complex congenital heart defects, the extent of muscle damage that occurs following a heart attack, and coronary-artery narrowing, together with the blood flow changes it fosters.

It is also hoped that DSR eventually can be recruited for diagnostic services. Ritman points out that CT scanners currently take too long and emit too much radiation to be of much use in programs screening for such things as lung cancer. In contrast, he says, DSR ultimately could become the definitive scout for congenital heart lesions or early signs of lung cancer.

The same type of reconstruction technique used to picture body organs may also prove useful as the basis for mass screenings such as airports conduct in their searches for hidden weapons. What's more, there is no reason to suspect that other forms of radiation—microwaves or nuclear-magnetic resonance, for instance—might not replace X-rays in these alternative applications. Finally, Wood feels the instrument is so "ideally" suited for studying physiological changes induced by living in zero gravity that, "I am certain...that it will eventually be used in life sciences flight studies."

But the Mayo team invites others to speculate along with it. "DSR could be seen as a national resource," whose object is to aid studies of the heart, lung and blood in living systems. □



Ritman/Science

X-ray contrast material highlights coronary arteries in DSR*'s reconstructed X-ray image of a dog's heart (A). Second image (B) offers a slightly blurred two-dimensional representation of the same heart, generated from three-dimensional data. Image intensity of the heart's wall was electronically "dissolved" 83.5 percent (C) to highlight the coronary arterial tree. (This technique cannot be applied to actual radiographs, only to* DSR*'s reconstructed images.) The last frame (D) displays heart rotated 45 degrees from previous frame (C); new view unveils central coronary artery that had been obscured by the left coronary artery.*