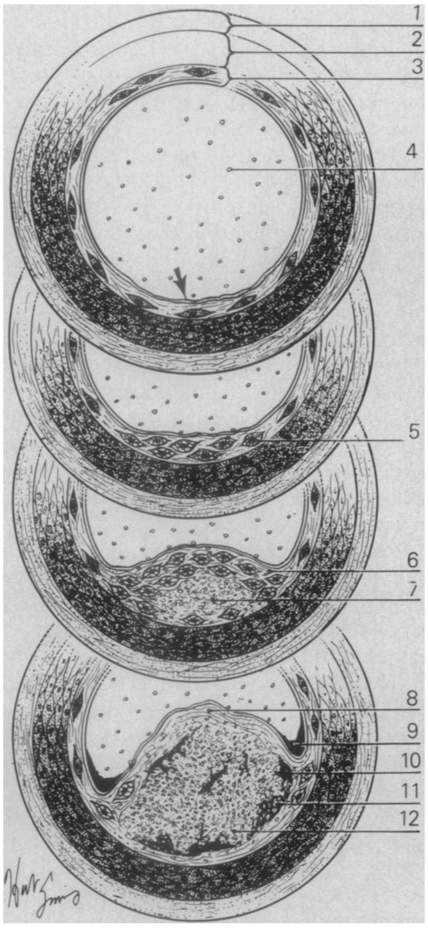
Sounding Out 3-D Interiors

Three-dimensional reconstruction may revolutionize ultrasound imaging of the cardiovascular system



Reproduced from DeBakey, Michael E. and Gotto, Antonio: The Living Heart, New York, David McKay Co., Inc., 1977, p. 111.

Diagram illustrates several forms of atherosclerotic lesions *that can develop in arteries. Top cross section shows layers of arterial wall: adventitia (1), media (2) and intima (3). Lipoproteins (4), which transport cholesterol through bloodstream, can enter damaged arterial lining (arrow) to stimulate growth and proliferation of smooth muscle cells (SMCs) seen in next cross section (5). In fibrous plaque (cross section second from bottom), most fats (7) are outside cells. Together with broken-down cells they form a core that is capped with collagen tissue and elastic fibers (6), and fat-filled SMCs. A fibrous plaque may be transformed into "complicated lesion" (bottom cross section) through development of hemorrhage (10), blood clot (9) or the hardened tissue (11) formed by deposits of insoluble salts. Complicated lesions, the most dangerous, contain a core of lipids (12) – mainly cholesterol and cholesterol esters – in the center of dead tissue (8).*

By JANET RALOFF

A medical imaging system that offers three-dimensional renderings of the heart and arteries is one of the newest space-program spinoffs. Developed to monitor temporary spaceflight-induced changes in the hearts of astronauts, this system is already providing cardiologists at the University of Southern California a low-cost noninvasive means of tracking changes in the development of atherosclerosis (hardening of the arteries) in humans.

The technique, an adaptation of conventional ultrasound imaging, uses sophisticated computer processing to mesh digital data representing a series of two-dimensional cross-sectional ultrasound images with the position and spatial-orientation coordinates of the ultrasound probe as each image was taken. What results is an ability to compute three-dimensional reconstructions of the human heart or selected arteries. Using computer-graphics techniques, the data are manipulated to produce crisp two-dimensional representations — with appropriate shading to suggest a third dimension — of the imaged structure.

The reconstructed image, or ultrasonic cast, can be selected to display the structure as it would appear from any orientation angle the researcher selects. Arteries can be visualized as if a plaster cast of them were suspended in space. "When the technology gets a little cheaper, every cardiologist in the country will have one of these in his office, not just in [his] hospital," predicts John Hestenes, one of its developers at the National Aeronautics and Space Administration's Jet Propulsion Laboratory in Pasadena, Calif.

More than 75 percent of all cases of "heart disease" actually affect the arteries. And most of these result from atherosclerosis, a form of arteriosclerosis in which lipids — fatty substances including cholesterol — adhere to the inner surface of arterial walls. The disease usually involves the innermost and medial layers of the arterial wall, and occurs most often in medium- to large-sized vessels.

Atherosclerosis can lead to strokes, heart attacks, angina pectoris and other forms of heart disease. What causes it is still not fully understood; theories abound, yet none accounts satisfactorily for all manifestations of the disease.

Lipid deposits characterizing this disease tend to be nodular and localized, rather than evenly deposited films lining the entire vascular network. Sites where deposits occur are called lesions. Severe lesions involving "plaque" — lipid deposits that extend into the blood vessel passageways — may end up totally blocking the flow of blood through an artery. Other times, the disease may cause a ballooning out of the arterial wall, known as an aneurysm.

In their book *The Living Heart* (McKay, 1977), heart surgeon Michael DeBakey and Antonio Gotto, who have researched the role of blood fats in coronary disease, suggest that atherosclerosis in this country probably begins early: "Post-mortem studies carried out on young soldiers killed in the Korean war indicated that many of them had a significant degree of blockage due to atherosclerosis of coronary arteries by the time they were in their mid-twenties."

In charting the development of atherosclerotic lesions, angiography has become the diagnostic standard. The procedure involves threading a thin plastic tube, or catheter, through a vein or artery until it has been positioned properly. Then a harmless dye, opaque to X-rays, is injected. Subsequent X-rays of the injected region highlight the blood-vessel passages — revealing arterial blockages, constrictions and other signs of atherosclerotic disease. But as angiography involves minor surgery (to place the catheter), X-rays and an injection of dye, it is not without risk; in fact, an average of two patients in every 1,000 die from complications associated with the procedure.

Far safer is echocardiography. An adaptation of submarine sonar, it involves bouncing high-pitched "ultrasound" waves off arterial structures, and using data from the returned echoes to noninvasively view them. Such sonographic images, however, can prove murky. At least as important, it is virtually impossible to picture precisely the same view in succeeding visits to the doctor, making the comparison of structural features over time difficult.

Recently, William Moritz, an electrical engineer at the University of Washington in Seattle, began attaching a spark-gap device to the ultrasound probe. (The probe, which looks something like a standard telephone receiver, is placed against the skin over the structures to be viewed. Inside it, a piezoelectric crystal vibrates when excited, creating the ultrasonic pulses used for imaging.) Three spark gaps, mounted in a triangular configuration, are fired in sequence. Noise they emit is picked up by a trio of microphones on the ceiling of the room (which have been mounted at three corners of a square-shaped frame). Listening to the firings, and coordinating those pulses with the time each signal was emitted, allows a computer to calculate the position and orientation of the ultrasound probe in relation to the patient's body, and to then assign reference coordinates to each sonogram indicating how the probe had been positioned when it was taken.

Hestenes, who has worked with Moritz, decided to take the procedure one step further. He developed computer software (programming) that integrates the digitized videotape ultrasound images and ultrasound-probe position readings. What results are three-dimensional coordinates describing the arterial structures observed (the same technique can be applied to multiple images defining the heart). Drawing from this data base, a computer can then reconstruct any view of the structures selected, and project it onto television monitors. The reconstruction process is similar to that used in computed-axial-tomography (CAT) scanning. But unlike CAT scans and conceptually related systems, such as the Dynamic Spatial Reconstructor (SN: 11/1/80, p. 284), three-dimensional ultrasound imaging is done without use of ionizing radiation or injection of contrast dyes.

David Blankenhorn is a USC cardiologist using this ultrasound system in an experiment to determine whether reducing blood-cholesterol levels in men who have undergone coronary-bypass surgery influences the course of their atherosclerosis. Though angiography is relied upon as the primary imaging technology, ultrasound monitoring has also been performed on these patients for the past three years. And over just the past few months, three-dimensional reconstruction of the ultrasound measurements has begun.

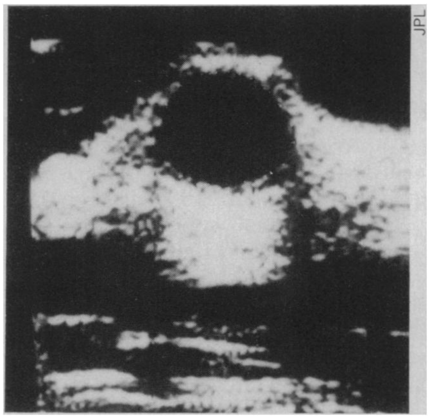
It's still too early to compare results from the two techniques in this project, Blankenhorn says. However, during experiments imaging arteries in "phantoms" (material used in biological experiments that approximates as closely as possible the density and effective atomic number of living tissue), he said three-dimensional ultrasound reconstructions had been compared with angiograms, "and they're pretty good."

"The problem with currently available ultrasound equipment," Blankenhorn says, "is that their view is too restricted—they do not reach in deep enough to see a number of important vessels." What's more, he adds, in its current state of development, ultrasound "will not resolve the fine detail that X-rays [angiography] will. But on balance, ultrasound has the advantage that it is noninvasive, so you can use it as often as you want." And that's "a compelling advantage," he points out.

Already three-dimensional ultrasound shows promise for replacing angiography in the imaging of peripheral (noncardiac) vessels—perhaps as a routine diagnostic procedure. And it's possible, Blankenhorn suggests, that several experimental procedures, such as swept-frequency ultrasound, may extend the depth with which ultrasound can penetrate tissue and still yield clear images.

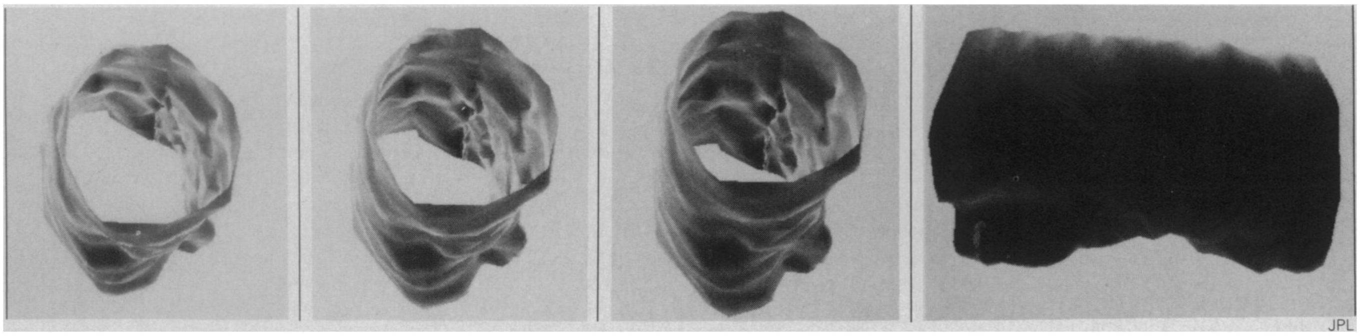
"We are visualizing the carotid [neck] artery," Blankenhorn says, "because that's the one you can see really well with ultrasound equipment that's available for clinical use." Today the higher frequencies that permit good resolution simply "don't penetrate well into tissue," he explains, "so deep-lying arteries aren't well visualized." But the carotid — lying right under the skin, or close to it, for a span of about two and a half inches in the neck—presents no obstacles. And it's an important window on the cardiovascular system, since lesions in this artery may lead to strokes or stroke-like symptoms.

The usual procedure is to coat the surface of an ultrasound probe with jelly, then to rub it about the neck. "As you do this, you see on a TV screen the [nonreconstructed] picture of the artery," Blankenhorn explains. Though in theory an investigator could scan the probe along the neck free-hand from chin to shoulder (roughly 100 sonograms are needed for each reconstruction), Blankenhorn fears the computer might have a hard time integrating the data. Therefore, in conjunction with the JPL team, his laboratory at USC has developed "a mechanical rack-and-pinion device" to take the sonograms. By taking each cross-sectional sonogram exactly parallel to the neck at 0.2-millimeter intervals, it greatly simplifies the computer's data-integration problem. The mechanical arm makes two full sweeps over the neck—first in one direction, then again at what would amount to a right angle from the initial run. In fact, the second run may not even be necessary, Blankenhorn points out, because a full three-dimensional reconstruction can be developed from any single run.


JPL

Training is required to "read" echocardiographs; this one shows carotid artery.

The real advantage of three-dimensional ultrasound, Hestenes says, "is that a person gets the same results regardless of how he holds the probe." As long as they take enough sonograms of the region, "all investigators will get the same reconstruction," he says; "therefore, this method is reproducible." In fact, he adds, by working with several medical centers and one of the ultrasound-equipment manufacturers, "we probably have helped a lot of people


JPL

JPL's three-dimensional computer-generated casts, or reconstructions (shown above), were developed from digital data representing 100 or more standard echocardiographic (two-dimensional ultrasound) images of a lesion-free carotid artery.

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see the light—that [three-dimensional ultrasound] must be done in order to get reproducibility."

What's more, angiograms depict the presence of the injected contrast agent (dye), not the arterial wall. "In ultrasound, you image the arterial-wall structures themselves," points out James Rooney, who works with Hestenes on the three-dimensional-reconstruction project at JPL. "This is important because there are differences in elastic properties of the arterial wall and the blood that's flowing through it. In addition, one can obtain detailed information on the arterial wall itself which is not available through any X-ray technique," he told SCIENCE NEWS. Adds Blankenhorn, "There is some reason to believe that ultrasound can visualize both sides of a blood vessel—both the innermost layer and the outermost layer of a vessel — thereby telling you how thick it is."

It's interest in measuring heart-wall tissue, however, that prompted Hestenes and Rooney to develop this system for NASA. Studies made by NASA scientists have shown that in response to space flight, an astronaut's heart will undergo important changes. "For example," Hestenes says, "it changes its function, its dynamics, it even loses some weight (over the duration of flight, muscle is lost, it atrophies). Also the internal volume of the heart — in the left ventricle — will diminish under zero-gravity conditions. When a person comes back to earth he has to readjust so that the internal volume will increase." Of course, with U.S. astronauts spending only a week or so in space at a time now, there are "no drastic changes" Hestenes explains. "But in long-term flights, like manning space stations, we may have to worry about what zero gravity is doing to the heart."

Under zero gravity, the heart doesn't have to work as hard; it is no longer fighting gravity in its efforts to pump blood up from the feet toward the head. In addition, blood distributes itself differently — there's less in the legs, more in the stomach, arms and head. (In fact, Hestenes notes, "the face sort of puffs up" as a result.) Because of these changes, "the actual motion of the heart can change. And as the demands on it change," Hestenes points out, "so the function will change slightly."

Currently measurements are made of the astronauts' hearts just prior to spaceflight, the day after they arrive back on earth, and again a week later — all in an attempt to understand cardiovascular readjustment. The goal of the NASA project is to have three-dimensional ultrasound-imaging systems portable enough to ride along on space-shuttle flights. "We'd like to see a device like this in a space station," Hestenes says. "And when that happens, I'll retire with a smile on my face." □