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- VEIN GRAFT SURVEILLANCE USING 3D ULTRASOUND IMAGING
- MEASUREMENT OF ABDOMINAL AORTIC ANEURYSMS WITH 3D ULTRASOUND
- MUSCLE BLOOD FLOW ASSESSMENT WITH 3D ULTRASOUND IMAGING
- AUTOMATED MEASUREMENT OF FLOW-MEDIATED VESSEL DILATION

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Quantitative evaluation of anatomy from medical images has applications in clinical diagnosis, monitoring, drug development and research. Ultrasound is a safe, non-invasive and relatively inexpensive imaging modality that produces a tomographic image of a thin tissue slice within a region of interest. Standard real-time ultrasound systems, however, do not maintain a record of the spatial relationship between sequential 2D images. Therefore, measurements of size and shape are often based on geometric assumptions and may be operator dependent.

We use a custom ultrasound imaging system that preserves the relationship of the 2D image planes in space, thereby allowing reconstruction of structures in a 3D coordinate system. Accurate 3D reconstructions provide better quantification of geometric parameters, enhancing comparisons of data both over time and between imaging modalities. In addition, realistic and intuitive displays can assist in the transfer of information between the multiple groups often involved in patient care.

Vein Graft Surveillance Using 3D Ultrasound Imaging

Vein grafts are placed to bypass diseased arteries in the lower limb when symptoms such as pain during walking, rest pain, and tissue necrosis occur. While vein grafts provide effective relief of lower extremity ischemia for the majority of patients, approximately 30-40% of these grafts fail due to focal stenoses caused by myointimal hyperplasia. Because these lesions can be effectively corrected, their early detection is crucial.

Our laboratory is developing 3D ultrasound imaging techniques for vein graft monitoring. Arteriograms and conventional ultrasound imaging produce only 2D views of vessels. Lesions at sites of complex geometry are difficult to monitor with 2D methods, and spatial relationships over time are not preserved. Three-dimensional imaging, however, can produce a full representation of the vessel geometry, allowing assessment of changes over time at specific sites.

Our 3D ultrasound imaging system is based on a standard ultrasound imager modified with a magnetic tracking system to register 2D ultrasound images in a 3D coordinate system. The tracking system records the location and orientation of the ultrasound scanhead during imaging, from which a 3D computer reconstruction of the vessel can be derived. Cross-sectional area measurements in planes normal to the center axis of the vessel are calculated from the 3D surface reconstructions.

We are using the 3D imaging methods to quantitatively track size changes in vein grafts over time. In a study of patch angioplasty revisions, lumenal narrowing documented by 3D scanning was not associated with consistent velocity changes on conventional duplex graft surveillance scans. Therefore, the 3D method provides documentation of anatomical changes in areas of complex geometry where velocity measurements are

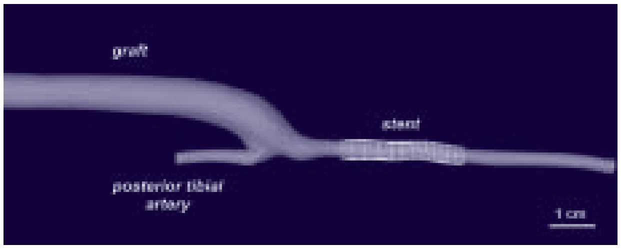

FIGURE 1: 3D surface reconstruction of the distal anastomosis of a bypass graft and a stent placed distal to the graft to treat a stenosis. The scan was performed one week after placement of the stent. The vessel lumen is displayed as a surface; the stent is displayed as a mesh surrounding the lumen.

difficult to perform and interpret. Quantitative monitoring of vein graft morphology may provide a means to distinguish normal remodeling from pathologic changes that threaten vein graft patency.

We are also able to track changes following endovascular interventions. Figure 1 shows a 3D reconstruction of the distal anastomosis of a bypass graft with a stent placed distal to the graft to treat a stenosis. Sequential follow up studies show progressive narrowing of the vessel within the stent (Figure 2). Enhanced displays of the 3D computer reconstructions are also being developed for more intuitive presentation of vessel anatomy. Figure 3 shows the proximal anastomosis of a jump graft with a calibrated '3D tape measure' placed along the center axis of the graft. Its fixed width of 2 mm provides a reference for vessel diameter, and grid marks are placed at 1-mm and 1-cm intervals to provide distance references. In addition, the skin surface is displayed along the track of the ultrasound transducer to indicate the depth of the graft.

Ultrasound is an attractive imaging modality for screening and monitoring abdominal aortic aneurysm patients since it does not involve radiation or contrast agents.

Measurement of Abdominal Aortic Aneurysm with 3D Ultrasound

Abdominal aortic aneurysms (AAAs) are dilations of the aorta occurring between the renal and the iliac arteries. Reliable quantitative evaluation of AAAs is required both for diagnosis and in the follow-up studies needed to avoid life-threatening rupture. Small aneurysms enlarge at an average rate of 0.5 cm in diameter per year, and they require close tracking by serial measurements to assure suitable treatment before risk of rupture is significant. A recent development in AAA treatment is endovascular repair, which is a minimally-invasive procedure to exclude the aneurysm from the circulation.

In contrast to the traditional open surgery, an endovascular graft is deployed using a catheter system

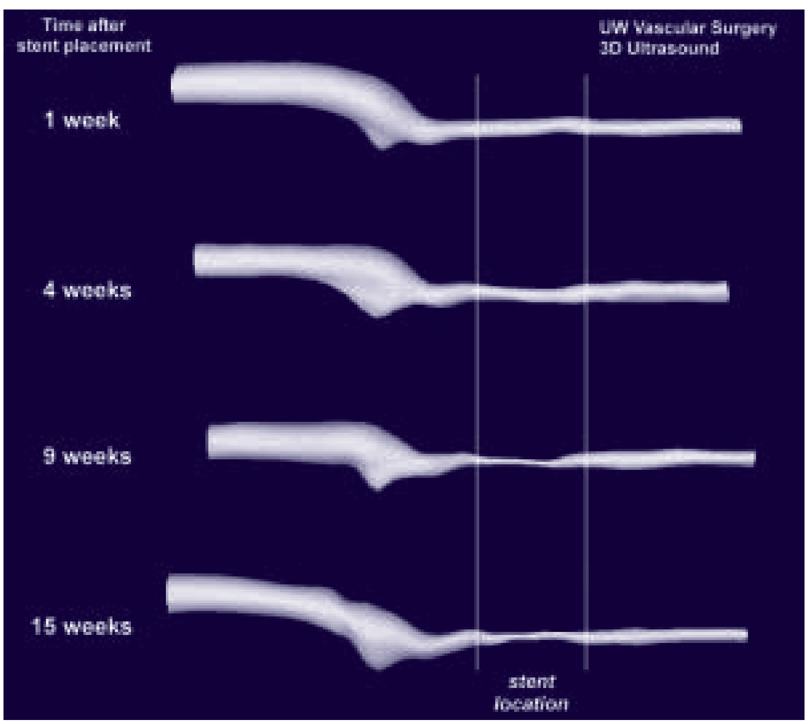

FIGURE 2: Serial 3D surface reconstructions of the site of the stent repair shown in Figure 1. Narrowing of the lumen within the stent is evident.

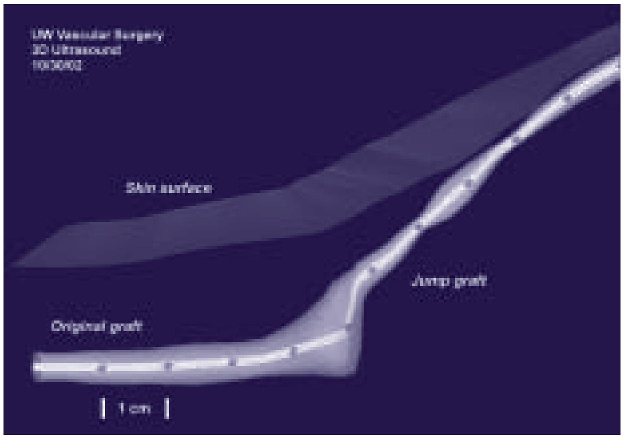

FIGURE 3: Three-dimensional surface display of the proximal anastomosis of a jump graft. A surface strip constructed along the center axis serves as a 3D tape measure to provide references for vessel width and length. The tape measure surface is 2 mm wide, with 1-mm grid marks and diamond markers at 1-cm intervals. The skin surface is displayed as a sheet to indicate the depth of the vessel.

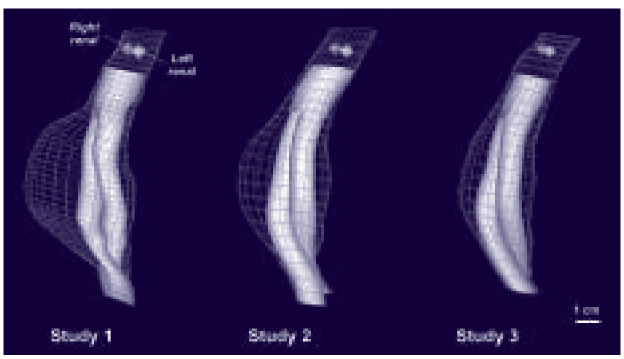

FIGURE 4: Serial study of an AAA repaired by an endovascular graft. The 3D reconstructions show both the aneurysm (outer mesh) and the graft (inner surface). The studies were performed 1) 2 weeks, 2) 6-months, and 3) 1 year after graft placement. Diamond markers show the origins of the renal arteries.

passed into the aorta through the femoral arteries. This procedure is associated with significantly reduced morbidity and recovery time. However, extended post-treatment monitoring is generally required to ensure that the endograft is stable and that there are no leaks. While decrease in aneurysm size indicates its successful exclusion from the circulation, post-implant expansion indicates the presence of a leak and a risk of aneurysm rupture.

Ultrasound is an attractive imaging modality for screening and monitoring AAA patients since it does not involve radiation or contrast agents. However, dimensional measurements made with conventional 2D ultrasound are sensitive to image plane orientation. In addition, the orientation and placement of the imaging planes change from visit to visit, which contributes to measurement variability in studies over time. Therefore, we are using the 3D ultrasound imaging system described above to generate computer reconstructions of the aorta from which quantitative measurements can be extracted. Computer reconstructions of an AAA are presented in Figure 4 for a series of 3D ultrasound studies after endovascular repair, showing shrinkage of the aneurysm sac. We are currently investigating automatic computer segmentation methods to improve the potential for practical application of the 3D ultrasound imaging method.

Muscle Blood Flow Assessment with 3D Ultrasound Imaging

A National Space Biomedical Research Institute project under Dr. Martin Kushmerick in the Department of Radiology is investigating the use of 3D ultrasound to measure blood flow changes in muscle in response to exercise. Three-dimensional scans of the anterior tibial muscle were performed after several minutes at rest, and during the 15-minute period of recovery following one minute of exercise (foot dorsiflexion/plantarflexion). At each time point, 120 images were captured over an approximately 5-cm length of the muscle. The position and orientation of the ultrasound scanhead was recorded during image acquisition by the magnetic tracking system described above.

Within the scanned volume the 3D reconstructions showed a large vasodilation after exercise (Figure 5) which returned to baseline (Figure 6). The time course of these changes could be fitted to an exponential decay. In nine subjects, the mean recovery time constant was 2.3 ± 1.1 minutes. The initial response and time to recovery may provide objective measures of the efficacy of countermeasures designed to reduce muscle atrophy during extended spaceflight.

Automated Measurement of Flow-Mediated Vessel Dilation

Ultrasound measurement of flow-mediated vessel dilation has been proposed as a means to assess changes in endothelial function associated with atherosclerosis, hypertension and heart failure. Typically, the diameter of the brachial artery is measured at a single time point after release of a blood pressure cuff to quantify the flow-mediated response to temporary ischemia. This measurement, however, does not necessarily represent the point of maximum dilation. As part of a research study of preeclampsia conducted by Dr. Darcy Carr in

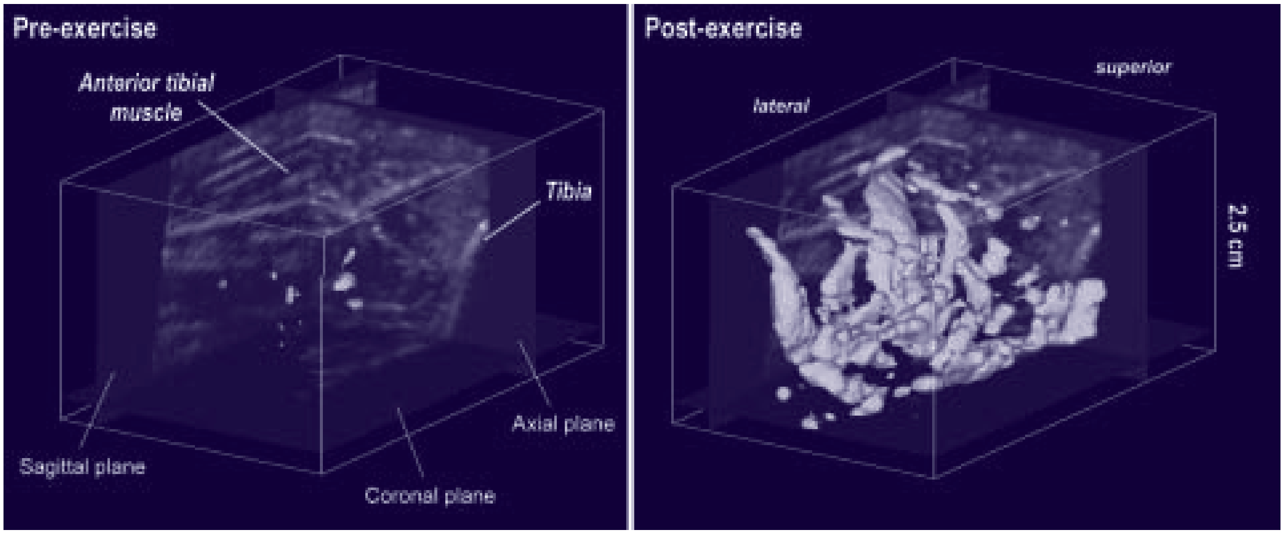

FIGURE 5: 3D volume reconstructions of the anterior tibial muscle before exercise (left) and immediately after exercise (right). Gray-scale and color data, representing tissue and blood flow respectively, were reconstructed separately and re-combined in a single display as orthogonal slices (anatomy) and surface rendering (blood flow). Voxel size = 0.5 mm.

the Department of Obstetrics and Gynecology, we have developed an automated image analysis method to measure the response of the vessel as a function of time after transient ischemia (Figure 7). This method provides documentation of the vessel response without assumptions regarding the time of maximum dilation, and the automated edge detection algorithm reduces observer variability associated with manual measurement.

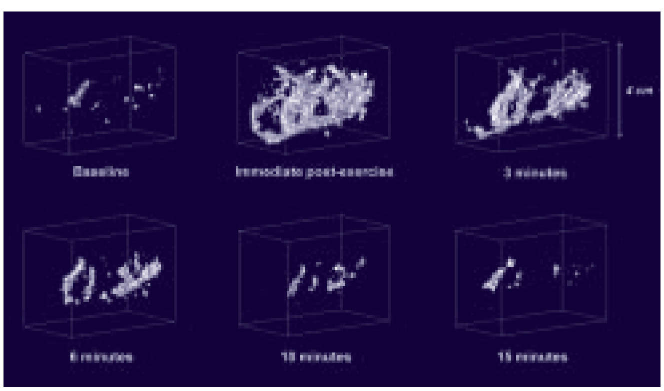

FIGURE 6: Series of volume reconstructions for 3D ultrasound scans acquired during a single exercise experiment. A baseline scan is obtained after several minutes of rest. Scans are then acquired immediately after exercise and at 3, 6, 10 and 15 minutes after exercise. The color voxels, representing blood flow, are segmented from the gray scale background and displayed as surfaces. Voxel size = 0.75 mm.

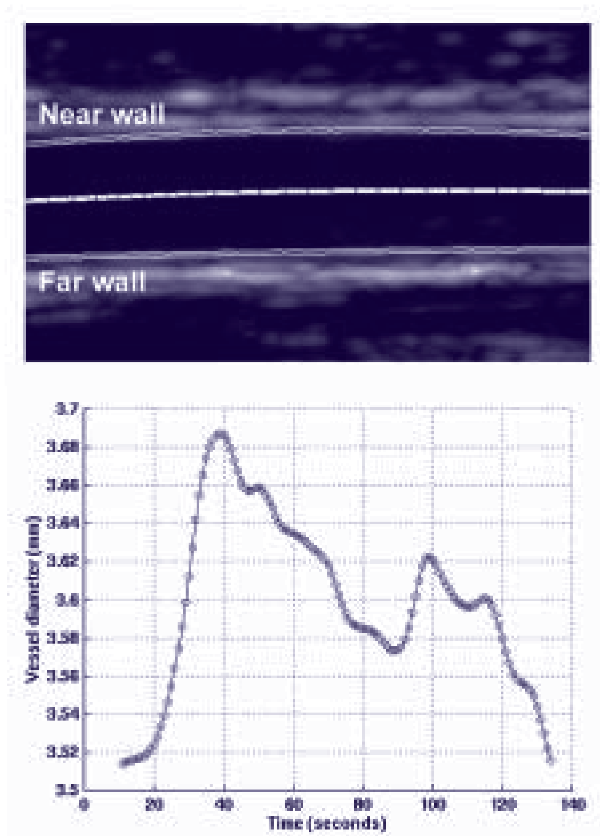

FIGURE 7: A longitudinal image of the brachial artery is shown at the top, with the locations of the vessel walls superimposed as detected by automated image processing. The diameter is measured along lines perpendicular to the vessel center axis; the measurements are averaged over the length of the vessel segment shown. The flow-mediated response of the brachial artery is plotted below as a function of time after release of a blood pressure cuff (time = 0).

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