3-D ULTRASOUND IMAGING OF THE PROSTATE

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Abstract: 2-D viewing of 3-D anatomy limits our ability to quantify and visualize prostate disease and is partly responsible for the reported variabilities. This occurs because: (i) the diagnostician must integrate multiple 2-D images in his mind during the procedure, leading to inefficiency and variability; (ii) The 2-D ultrasound image represents a thin plane at some arbitrary angle in the body, making it difficult to localize the image plane. To overcome these deficiencies, we have developed a 3D ultrasound system to image the prostate. Our 3-D ultrasound imaging system consists of: a conventional ultrasound machine and transducer; a custom-build assembly for rotating the probe under microcomputer control; a microcomputer with a video frame grabber; and software to reconstruct and display 3-D images. In this paper we will describe the details of the 3-D imaging approach and its use for imaging the prostate in 3-D and its accuracy in measuring prostate volume.

LIMITATIONS OF CONVENTIONAL ULTRASOUND

At present, the most commonly used screening techniques for prostate cancer are the digital rectal examination and the prostate specific antigen (PSA) test. The role of PSA testing in the diagnosis and monitoring of prostate cancer is well established. A simple blood test, used to measure the level of PSA secreted by the prostate gland, can signal the presence of prostate cancer in a man who has no other symptoms of prostate abnormality. However, the use of PSA for the early detection and staging of prostate cancer remains controversial, and forms the subject of many clinical and scientific investigations.1,2 To improve the clinical utility of the PSA test, many investigators have attempted to correlate the PSA level with the prostate volume. It is believed that measuring the prostate and/or tumor volume is important in interpreting the PSA assay level and any change in response to therapy. Currently, quantitative estimation of the prostate or tumor volume is usually performed by measuring its height, width, and length from two orthogonal 2D TRUS images and calculating the volume of the corresponding ellipsoid. However, this method may potentially lead to inaccurate and variable results.

3D TRANSRECTAL ULTRASOUND IMAGING SYSTEM

To overcome these limitations of conventional TRUS, we have developed a 3D TRUS imaging system.10,11,12 The system consists of three elements: (i) a conventional ultrasound machine with a transrectal ultrasound transducer; (ii) a microcomputer with an 8-bit video frame-grabber; and, (iii) a motor-driven assembly to hold and rotate the transducer. The TRUS probe is mounted in the probe holder assembly. When activated, it is rotated around its long axis by a computer-controlled motor. The data necessary for reconstructing a 3D image data is acquired by collecting a series of 2D B-mode images as the probe is rotated at constant speed. For a typical
acquisition, the probe is rotated through about 80° while 100 images are collected at 15 images/sec, so that the entire data acquisition can be completed in 8 seconds. For larger prostates, the total scanning angle is increased with a proportional increase in the scanning time. At pre-defined angular intervals of the probe, a region of interest (ROI) within the video image is digitized and stored in the computer memory. After a complete series of images is acquired, the image data are then reconstructed into a 3D image and displayed with interactive 3D visualization tools.10 For the results presented in this paper, we used an ATL Ultramark 9 ultrasound imaging system (Advanced Technology Laboratories, Bothell, WA) with a 5-MHz side-firing linear-array transducer. However, the system can be used with any ultrasound imaging system.

EVALUATION OF SYSTEM PERFORMANCE

Distance measurement: The accuracy of distance measurements was evaluated by imaging a 3D wire phantom. The phantom is composed of four layers of 0.25-mm diameter surgical wires, with 8 parallel wires per layer. The distance between layers is 10.00 ± 0.05 mm, as is the separation of wires within each layer. The wire phantom was scanned first with the wires placed parallel to the axis of rotation of the probe, (z-axis) and then with the wires oriented parallel to the x-axis. For each scan, 100 2D images were collected over 60°. After reconstruction of the 3D image, the distances between wires was measured and compared to the true values. The results of the distance measurement study showed that our 3D TRUS system had an accuracy of about 1.0%, since the mean measured wire separation is 10.10 mm and true mean wire separation is 10.00 mm. The precision of an individual separation measurement is about 1% for the A images and 2-3% for the B images.

Volume measurement: To evaluate the accuracy of volume measurements, we imaged a balloon filled with five different amounts of bath solution, and compared the measured volumes, derived from the 3D images, to the true volumes. The balloon was filled with five different volumes of water bath solution ranging from about 23 cm³ to 66 cm³, and imaged as used for imaging the wire phantom. Each image data set consisted of 100 2D images, scanned through 60°. After reconstruction, each 3D image was "sliced" to produce successive 2D images in planes spaced about 0.2 mm apart. For each 2D image, the balloon boundary was then manually outlined, and the number of pixels within the boundary determined. Multiplying the sum of these numbers (i.e. the total number of voxels within the balloon) by the voxel volume then yielded the measured volume of the balloon. The results showed that the volume measurements have a root-mean-square (rms) accuracy of 0.9% and an rms precision of 1.7%. Also, a least-squares regression through the origin resulted in a best-fit line with a slope of 1.0004 ± 0.0039 and a correlation coefficient of 0.99997.

Image resolution: The wire phantom was used to evaluate the system resolution, as measured by the full-width at half-maximum (FWHM) of the cross-sectional image of the wires. To determine whether the 3D reconstruction algorithm has degraded the image resolution, the same analysis was performed on the central 16 2D images of each scan, and the results compared. In both the axial and lateral directions, the excess of the 3D FWHM's over their 2D counterparts is essentially independent of y. The axial excess is always positive, with a mean value of 0.07 ± 0.02 mm, while the lateral excess is almost random in sign, with a mean value of 0.10 ± 0.11 mm. The axial resolution is only slightly (8%) degraded by the 3D reconstruction, while the lateral resolution is negligibly (3%) degraded.

REFERENCES