3-D ultrasound in action

One of the first applications of direct prostate visualization was in ultrasound-guided prostate seed implantation. The procedure involves using transrectal ultrasound to guide, in real time, the implantation of 80 to 100 or more radioactive seeds. This technique may be impractical, however, for external-beam radiotherapy due to the discomfort, time requirement and distortion of the prostate gland caused by the probe. Although transrectal ultrasound provides excellent imaging at implantation time, CT has been the modality of choice for postimplant dosimetry. Three-dimensional ultrasound may assist and make a significant improvement in determining the dose delivered during a course of brachytherapy.

The first generation of ultrasound-based image guidance—2-D transabdominal ultrasound—was the earliest approach to direct volume visualization. This technique promised rapid positional verification based on direct prostate visualization, thereby addressing inter-fraction organ motion. The approach allows for pretreatment verification of the prostate position relative to a reference CT.

Ultrasound's next generation of 3-D reconstruction enables visualization in ways that parallel other advanced radiotherapy imaging modalities like CT and MR. Early 3-D ultrasound systems used cross-modality comparisons for image guidance, while newer systems employ an ultrasound-to-ultrasound approach, resulting in a more robust system of displacement calculation and correction.[2] The workflow in these systems involves acquiring a reference ultrasound during CT simulation and, on a daily basis, acquiring ultrasound volumes prior to each treatment fraction. The prostate volume is defined by an assisted segmentation algorithm and is automatically compared to the previously acquired reference volume.

Since 3-D radiation treatment planning is based on 3-D CT data, it is normal to expect that positional verification would also rely on volumetric information. Surprisingly, ultrasound verification was based on 2-D ultrasound comparison until recently. While later generations evolved to 3-D ultrasound reconstruction, they still relied on comparing 2-D slices to the original CT slices.

THREE-DIMENSIONAL ULTRASOUND HOLDS GREAT POTENTIAL IN ITS ABILITY TO SUPPORT OTHER MODALITIES IN IGRT.

The most recent technologies compare 3-D ultrasound data to 3-D ultrasound data. The benefits are a more robust means of position verification, elimination of subjectivity associated with comparing 2-D images acquired from different modalities, and inclusion of all the volumetric information, namely interfaces to critical organs such as the rectum. Furthermore, 3-D ultrasound data makes CT-ultrasound image fusion a real possibility, providing the physician with a distinct advantage for better treatment planning target definition for the prostate and other soft-tissue organs.

Three-dimensional ultrasound also holds great potential in its ability to support other modalities in IGRT. Traditionally, transrectal ultrasound has been used prior to seed implantation to determine the required number of seeds. With its ability to quickly calculate organ size and dimensions while reducing procedure time and patient discomfort, transabdominal 3-D ultrasound can replace this function. Some head-and-neck protocols require repeat CTs to monitor tumor responsiveness. Ultrasound in the treatment room can offer an efficient alternative by providing daily volumetric information during each treatment fraction.

In conclusion, rapidly correcting for inter-fraction organ displacement, 3-D ultrasound's soft-tissue definition complements X-ray-based technologies to enable more conformal treatment of prostate cancers. ■

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CLINICAL CONSIDERATIONS	IGRT MODALITIES					
	X-RAY	X-RAY WITH MARKERS	CONE-BEAM CT	TOMO-THERAPY	CT-ON-RAILS	3-D ULTRASOUND
NONINVASIVE TECHNOLOGY Techniques requiring implantation of fiducial markers are invasive and require a special procedure room and urologist. Consider nonimvasive systems that can be used during both treatment planning and delivery.	X		X	X	X	X
NONIONIZING RADIATION For pretreatment target verification, some techniques require additional nontherapeutic radiation exposure for image acquisition. The additional dose is considered small but may be significant—difficult to justify under ALARP (as low as reasonably practible).						X
DIRECT ANATOMICAL VISUALIZATION FOR ACCURATE PATIENT REPOSITIONING Fiducial markers may not remain fixed, and a few points within the prostate may not provide critical information about organ size or shape. With very conformal techniques, the additional "safety" margin added to the target volume to account for error is small, especially in the rectal area. Verification of this border will become increasingly important as treatment techniques become more conformal.				X	X	X
HIGH-QUALITY TARGET VOLUME DEFINITION Visualizing the prostate base and apex using CT alone is difficult. MR can help, but access is limited and fusing MR to CT images is time-consuming. Ultrasound's availability in the CT-sim room can improve target volume definition—especially in the prostate base and apex. When defining prostate volumes vs. CT, ultrasound provides accuracy similar to that of MR.[1]						X
LOW IMPACT ON THROUGHPUT (PRETREATMENT POSITION VERIFICATION IN UNDER TWO MINUTES) Historically, corrections for organ misalignment were performed after treatment—prior to the next day's treatment. Now that pretreatment verification is required with conformal therapy, this must be achievable without significantly hindering throughput.						X