
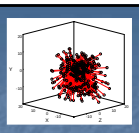
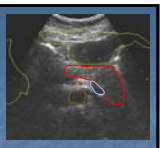

Ultrasound Guided In-Room Imaging for Localization

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University of Utah – Huntsman Cancer Institute

Acknowledgements

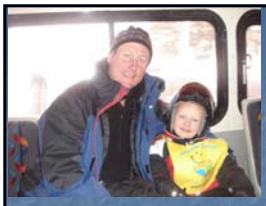
- Varian
- Resonant
- Nomos
- Martin Fuss MD

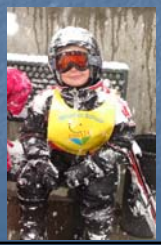
US Guidance Experience

- Started USG 2000 – Fall 2005 (UTHSCSA)
- 3 US Guidance Units (Nomos BAT)
- 9000+ patient alignments
- Evolved system to use in liver and pancreas
- Mistakes? We've made them all!

Redneck

In Texas






Monty Python's Holy Grail

Learning objectives

- Rationale for In-Room Guidance
- Rationale for US In-Room Guidance
- The USG Process
- Key components of the process
- QA considerations
- Dosimetric implications
- Outcome implications
- Other sites of application

Overview

- Rationale for in room Image Guidance
- Rationale for in room Ultrasound (US) Guidance
- The US Guidance Clinical Process
- Key components of the Process
- QA Considerations
- Dosimetric implications
- 'Outcome' implications
- Applications other than prostate

Why do we need in-room imaging?

Positional variation of the prostate gland within the pelvis

Balter et al. IJROBP 1993	12 mm (95% CI)
Roach et al. IJROBP 1994	7.5 to 22 mm (non-uniform)

CT simulation Day x of RT

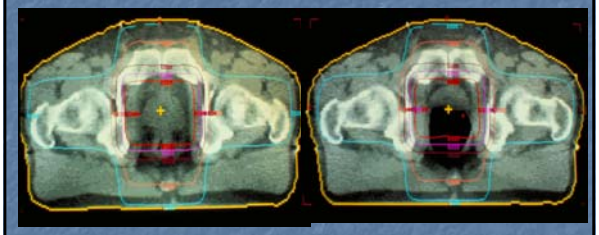
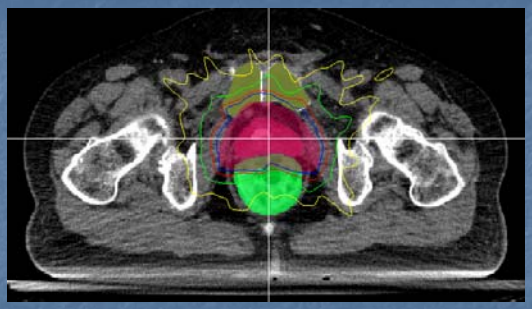
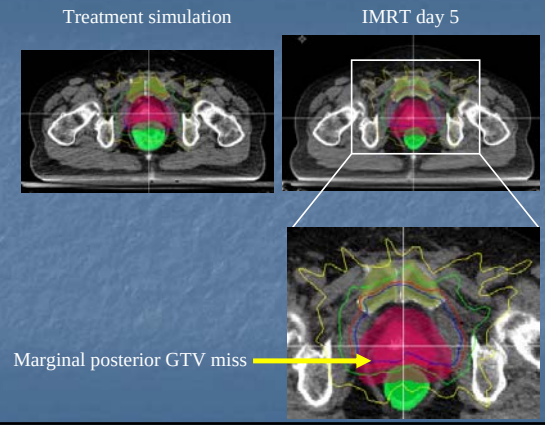


Image courtesy of Dr. David Hussey

Rationale for Image Guidance

- Setup to skin marks will not indicate target position, due to target movement relative to bony structures and skin
- Problem: tight safety margins and conformal dose distributions can lead to target miss





Causes of prostate positional variability

- Bladder filling
- Rectum filling
- Bladder and rectal contrast at RT planning
- Rectal catheter (plus inflated balloon)
- Overly full bladder
  - Tensioning/spasms of pelvic diaphragm

Potential dosimetric consequences of missing the target

- Delivered dose differs from prescribed dose
- If target moves posteriorly, then the posterior aspect of prostate can experience dose reduction
  - Malignant cell density if often very high in the posterior and apical aspect of the prostate
- Increased rectal wall dose
- Increased bladder floor dose
- Due to unpredictable changes on a daily basis, true dosimetry becomes uncertain

Potential advantages of image-guided targeting for prostate cancer RT

- Dose escalation
  - Improved bRFS, local control and survival
- Normal tissue sparing
  - Reduced acute and chronic toxicity

Intrafractional Motion

- A recent cine-MRI study showed that for patients with a full rectum there exists a 10% chance that the prostate will move 3-mm or more during only a 3 minute time frame following the commencement of treatment (Ghilezan et al 2005)
- Typical conformal treatments employing IMRT take longer than this to deliver.

Prostate is not the only abdominal/pelvic structure that moves.

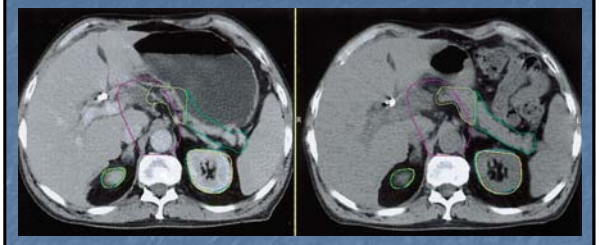


Figure 2. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue) and the target contour (violet) on the transverse non-contrast CT scan (right) project on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract) CT scan (left). The significant caudal translation of the pancreatic tail (light green) and parts of the pancreatic body (light yellow) owing to differential gastrointestinal distention are identified.

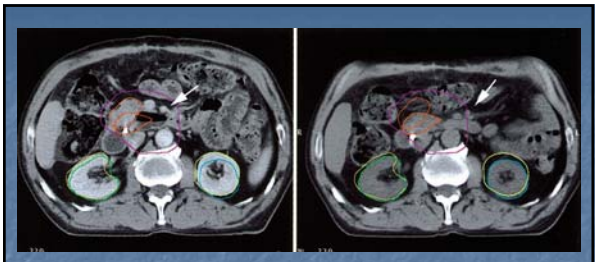


Figure 3. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue), pancreatic head contours (red), and the target contour (violet) on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract CT scan (left) project on the transverse non-contrast CT scan (right). The right-sided translation (11.2 mm) of the SMA at 15 mm from the origin (arrow) is illustrated. Note the displacement of the high-attenuation stent as a marker of a positional change of the pancreatic head. The CT registration shows a motion of the superior mesenteric vein parallel to the SMA and also indicates the caudal translation of the left kidney.

Characteristics of a successful in-room imaging approach for prostate

- Must be capable of directly ascertaining precise location of prostate
- Versus the use of unsuitable surrogates for position such as skin marks or bony anatomy
- Should require minimal amount of time
- The ability to at least visualize the intra fractional component of motion might be valuable, as well.

What are our options for acquiring targeting information for the prostate?

- Implanted fiducial markers
  - Daily planar image (portfilm, EPID, stereo pair, fluoro)
  - Interpretation of marker location (or automated fiducial location)
  - Objective and precise positional assessment of target (only)
  - Invasive procedure, radiation dose, marker migration, no intrafraction motion visualization (except for fluoro)
- In-room CT data (e.g. cone beam, in-room CT-on-rails, MV Tomo image)
  - Non invasive
  - 3D information (target and critical structures)
  - Radiation dose, image quality, intrafractional motion visualization?

What are our options for acquiring targeting information for the prostate?

- Implanted transponders
  - Real time assessment of target location (only)
  - Objective and precise real time positional assessment of target
  - Intrafractional motion assessment while treating
  - Invasive procedure
  - Beacon migration?
  - Expense?
- Ultrasound guided targeting
  - Non invasive
  - 'Real time' assessment of target and critical structure location
  - Intrafractional motion visualization, depending on method
  - Inter-user variability in positional assessment, depending on method
  - Unfamiliar imaging modality

Ultrasound Guidance Characteristics

- Must be capable of directly ascertaining precise location of prostate, versus the use of unsuitable surrogates for position such as skin marks or bony anatomy
- Should require minimal amount of time
- The ability to at least visualize the intra fractional component of motion might be valuable, as well.

Ultrasound Guidance Rationale

- Must be capable of directly ascertaining precise location of target, versus the use of unsuitable surrogates for position such as skin marks or bony anatomy
- Lattanzi et al 1999, Chandra et al 2003, Chinnnaiyan et al 2003, Little et al 2003, Fuss et al 2004, Kuban et al 2005)
- Publications critical of reproducibility.

Ultrasound Guidance Rationale

- Should require minimal amount of time
- Lattanzi et al 1999, Chandra et al 2003, Fuss et al 2004)

Overview

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- Applications other than prostate

In Room US Image Guidance Process

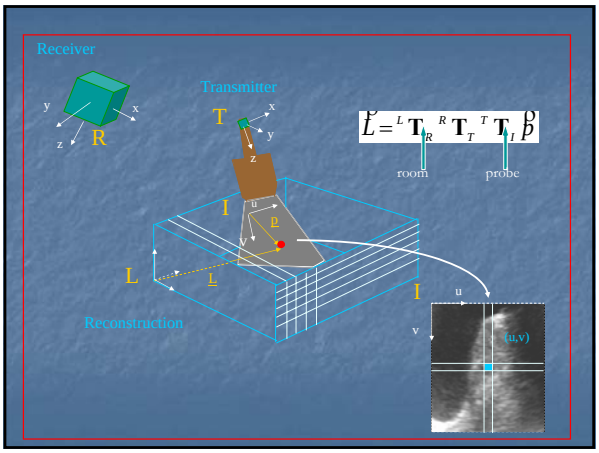
- We need to verify that the target and critical structures are in the same position(s) as they were for simulation.
- In-room verification of this allows us to verify correct position immediately prior to treatment.

In Room US Image Guidance Process

- The baseline for comparison is, obviously, the imaging data acquired in simulation (typically by CT).
- For the in-room acquired images to be useful for comparison with the CT simulation data, the in-room images must be mappable to a common reference frame.

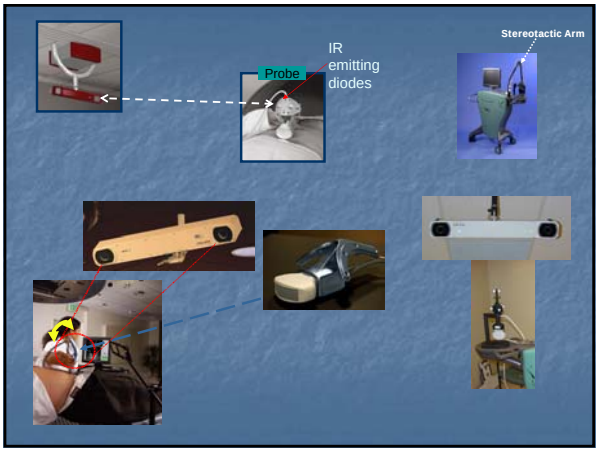
In Room US Image Guidance Process

- If the position and orientation of the US probe is known, in room coordinates, then the pixels within the US image can be assigned room coordinates, thus giving the structures visualized in the US image known locations in room coordinates.

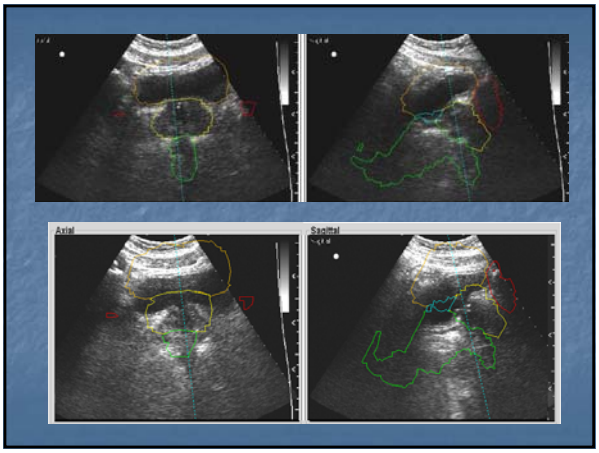


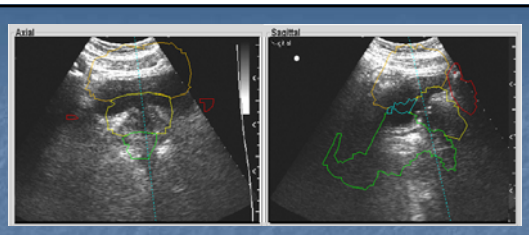
In Room US Image Guidance Process

- The system's understanding of the position and orientation of the US probe is typically achieved by some form of in-room tracking of the US probe.



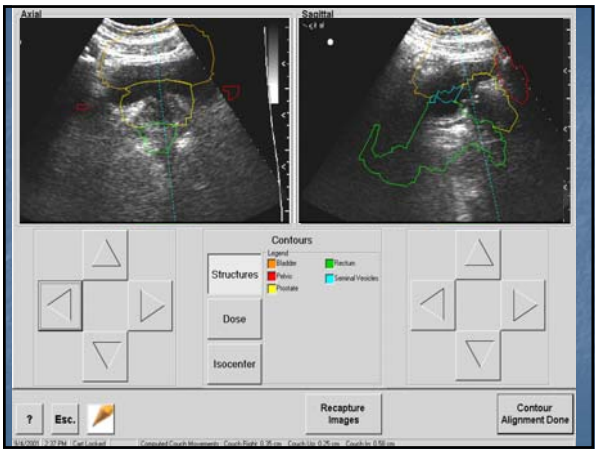
- By mapping the in-room-acquired US images to the same spatial reference frame as the simulation data set…
- We enable the direct comparison of the two data sets.
- This can be done, for instance, by overlaying the CT-Sim-derived contours of the target and critical structures onto the US image.



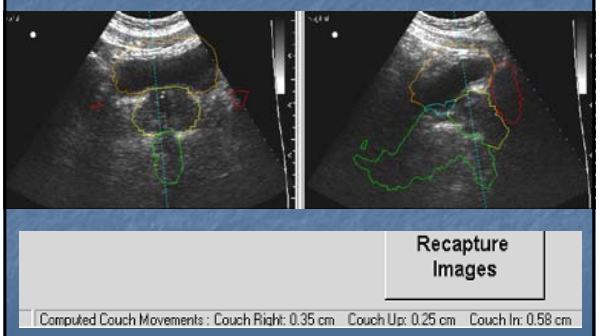


- The simulation derived contours are overlaid in room coordinates onto the US image *where they were at time of simulation.*
- This is where the system "expects" these structures to be in room coordinates, if you will.
- If the underlying US structure does not agree, this simply means that the structure has moved (relative to isocenter) since simulation.
- This information is useful, but what we really want is to know the 3D components of this misalignment and correct for it.
- How can we do this?

- In general, we can either assist the system in understanding how to correctly align the simulation contours with the in-room-acquired US image...

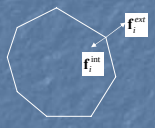


Ultrasound-based image guided targeting



- In general, we can either assist the system in understanding how to correctly align the simulation contours with the in-room-acquired US image...
- OR, we can have the system "automatically" find the relevant structures in the US image, and then compare their location with the "expected" location from simulation, and then compute the difference and required patient shifts.

Segmentation



$$\mathbf{f}_i^{tot} = w_i^{ext}\mathbf{f}_i^{ext} + w_i^{int}\mathbf{f}_i^{int} + \mathbf{f}_i^{d}$$

$$\mathbf{f}_i^{ext}(x,y) = \frac{2\nabla E(x,y)}{\max\left\|\nabla E(x,y)\right\|}$$

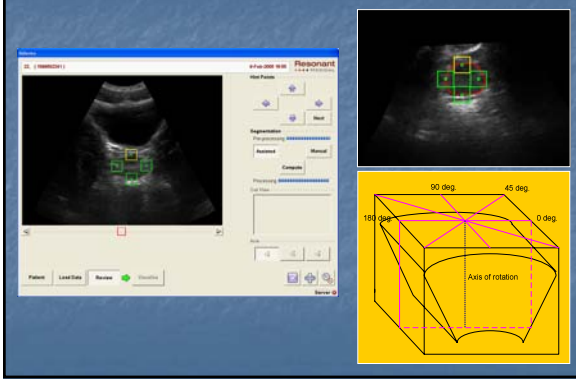
$$E(x,y) = \left\|\nabla\left(G_\sigma I(x,y)\right)\right\|$$

$$\mathbf{f}_i^{int} = \left(\mathbf{c}_i \cdot \hat{\mathbf{r}}_i - \left\langle \mathbf{c}_i \cdot \hat{\mathbf{r}}_i \right\rangle\right)\hat{\mathbf{r}}_i$$

$$\mathbf{f}_i^{d} = w_i^{d}\mathbf{v}_i$$

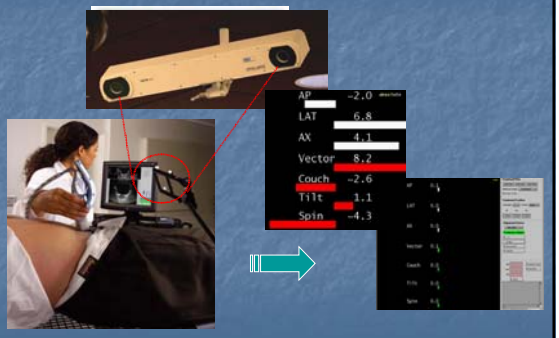
- External force pushes active contour towards gradients
- Internal force maintains constant curvature
- Damping force for stability
- Weights found empirically
- Contour evolves under forces until vertices come to rest

Segmentation



- However we determine the magnitude of displacements of the target, either by helping the system or by having it determine the shifts for us…
- We need to then implement the shifts.
- In other words, we now know that the target and critical structures are out of place relative to simulation…
- And we now need to move the patient to return the target and critical structures to the same location (relative to isocenter) as they were for treatment planning simulation.
- How do we implement the shifts?

SonArray-
3D Target Repositioning / Alignment



Vendor specific variations on the process

- Nomos BAT – Acquires US image data as 2 roughly orthogonal planar images.
- This allows for in-room, real time, visualization of motion.

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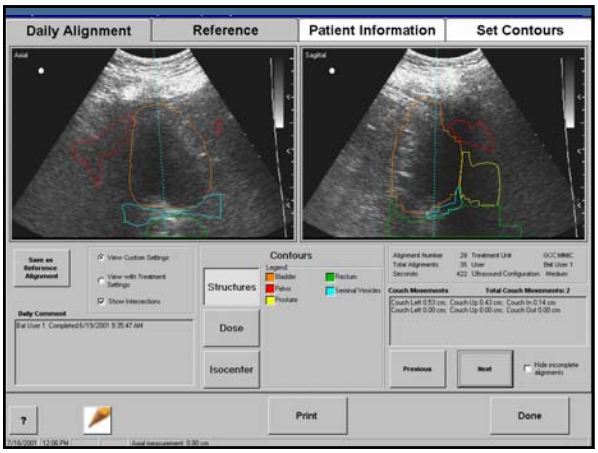
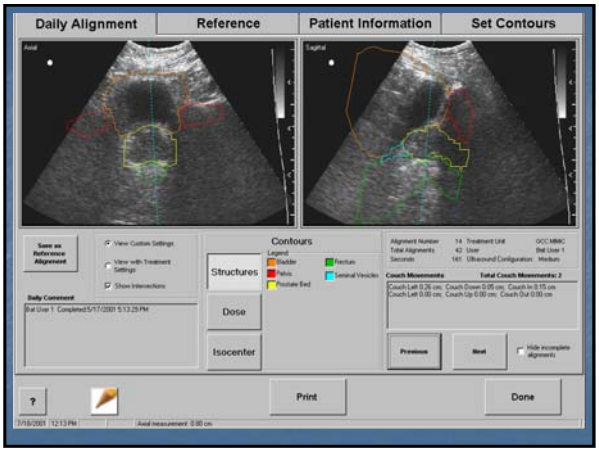
- Requires that the user acquire meaningful planar images.

Vendor specific variations on the process

- Nomos BAT – Acquires US image data as roughly orthogonal planar images.
- This allows for in-room, real time, visualization of motion.
- Requires that the user acquire meaningful images.
- What can go wrong?

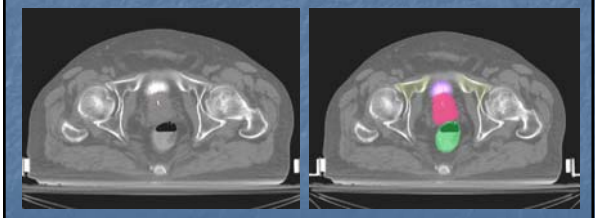




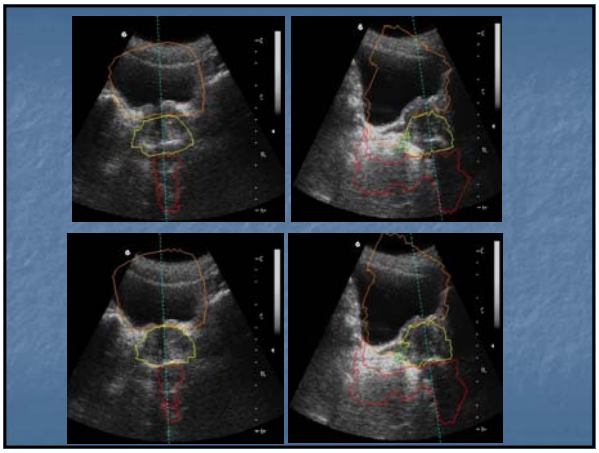
Ultrasound based image-guided targeting

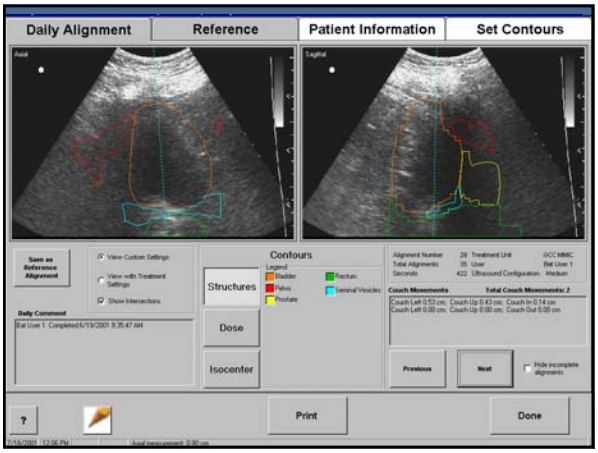
Target and organ-at-risk delineation

Is critical to the process.



Win or lose based on this step.





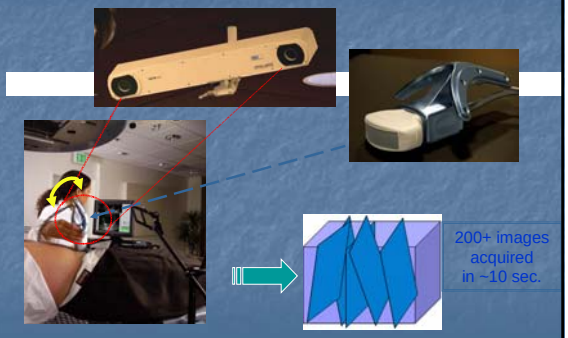
Vendor specific variations on the process

- Nomos BAT – Acquires US image data as roughly orthogonal planar images.
- This allows for in-room, real time, visualization of 3D aspects of target and critical structures
- Along with visualization of “intrafraction” motion.
- Requires that the user acquire meaningful images.

Vendor specific variations on the process

- Varian SonArray and Resonant Restitu – Acquire US image data as 3D array by sweeping the US transducer through the region of interest.

SonArray-
3D Ultrasound Image Acquisition



Vendor specific variations on the process

- Varian SonArray and Resonant Restitu – Acquires US image data as 3D array by sweeping the US transducer through the region of interest.
- This allows for building of a 3D array of US images that can be viewed (i.e. sliced and diced) in many different ways to facilitate determining how the in-room data set and the simulation data set may agree or disagree.

SonArray-
Spatially Correlated 3D Image Registration

Vendor specific variations on the process

- Varian SonArray and Resonant Restitu – Acquires US image data as 3D array by sweeping the US transducer through the region of interest.
- This allows for building of a 3D array of US images that can be viewed in many different ways to facilitate determining how the in-room data set and the simulation data set disagree.
- Does not necessarily afford the same opportunity to view treatment planning margins over moving US anatomy and must acquire sufficiently dense set of 3D planes.

Vendor specific variations on the process

- Varian SonArray and Nomos BAT – Compare the CT-derived contours to the US image
- Resonant Restitu acquires US images in the CT simulation suite, thus allowing for comparison of US reference images with the US in-room images.
- So concerns about how CT volumes of the prostate may differ from US volumes of the prostate can potentially be avoided.

Vendor specific variations on the process

- The auto segmentation of the US image structure set by Resonant's Restitu system should be evaluated for accuracy.

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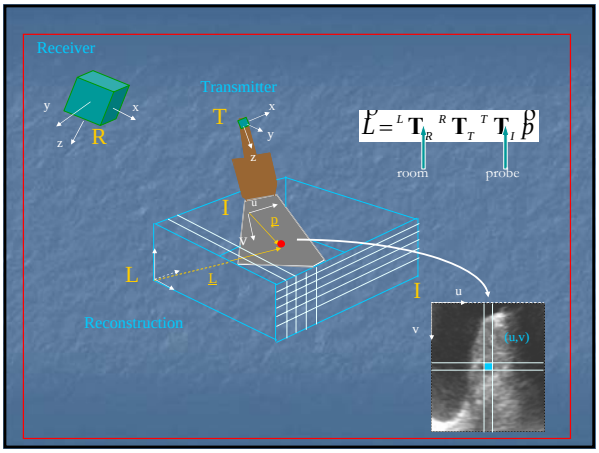
Key Components of the Process

- The ability to map the in-room US image data into a common coordinate system with the simulation images is all-important.
- This is accomplished, as discussed previously, by tracking the position and orientation of the US probe in the room.
- Small errors in the system's perspective on the probe position and orientation can manifest themselves as large errors in the coordinates assigned to structures in the US image.



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- The ability to map the in-room US image data into a common coordinate system with the simulation images is all-important.
- This is accomplished, as discussed previously, by tracking the position and orientation of the US probe in the room.
- Small errors in the system's understanding of probe position and orientation can manifest themselves as large errors in the coordinates assigned to structures in the US image.
- Whether probe position and orientation are determined from tracking the position of a stereotactic arm or through IR camera systems, these systems must be well maintained and calibrated.

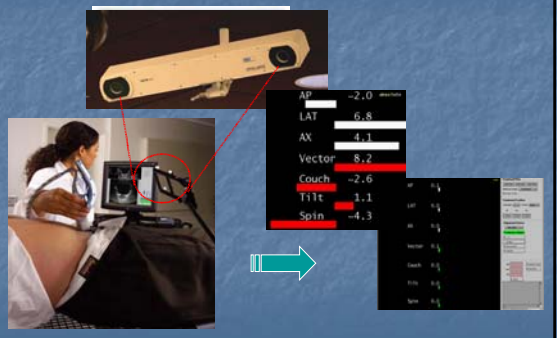
Key Components of the Process

- US Image Quality
- The inherent quality of the US image determines what structures are visible.
- Whether we assist the system in knowing how to align the simulation contours of target and critical structures (Varian and Nomos), or have the system do it for us (Resonant)...
- The quality of the images will effect the accuracy of the process.
- TG 1 (Report 65) describes methods for quantifying and maintaining US image quality.
- Additionally, the spatial integrity of the US image itself is very important to the accuracy of the process.

Key Components of the Process

- Table/Patient positioning feedback loop
- As mentioned previously, once we've determined the shifts necessary to return the target and critical structures to their same position, relative to isocenter, as was observed for simulation...
- We need to implement these shifts.
- These are performed by a feedback loop with the couch, as shown earlier...

SonArray-
3D Target Repositioning / Alignment



Key Components of the Process

- Table/Patient positioning feedback loop
- As mentioned previously, once we've determined the shifts necessary to return the target and critical structures to their same position, relative to isocenter, as was observed for simulation...
- We need to implement these shifts.
- These are performed by a feedback loop with the couch, as shown earlier...
- This system (camera and detachable couch mounted IR array OR stereotactic arm to detachable couch mount probe cradle) must be properly maintained and QA'd.

Key Components of the Process

- Individual User
- Regardless of the vendor system/process used, the user must operate the system.
- At the very least the user must acquire a valid data set for the region of interest.
- For the methods which use a 3D sweep of the US probe, the user must acquire a reasonably dense and well oriented data set.
- For the Restitu system the user must evaluate the quality of the automated image segmentation.
- For the Nomos approach, the user must acquire two planes which contain all the necessary 3D data, as mentioned earlier.
- If the method used requires the user to align the simulation contours with the US image from that day, the user must do this correctly.

Implementation and QA Considerations

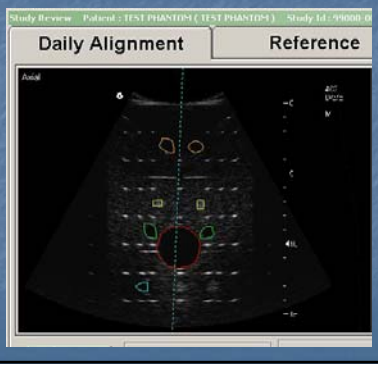
- Utilize the vendor's expertise at installation and commissioning.
- At installation and acceptance completion the system should be:
- Generating high quality US images
- Of high spatial integrity with regard to the in-room coordinate system.

Spatial Integrity

- End-to-End Test

Performed daily, prior to start of patient treatments.

Image quality baseline



User interaction with system

Inter-user variability

Recently critically and controversially discussed

Independent verification of ultrasound based image-guided radiation treatment, using electronic portal imaging and implanted gold markers

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Edward Seppi
Varian Medical Systems, Gintzon Technology Center, Palo Alto, California
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(Received 19 May 2003; revised 7 August 2003; accepted for publication 19 August 2003; published 14 October 2003)

The aim of this paper is to study the correction of prostate motion and position during external beam therapy. The correction was performed using a commercially available ultrasound-based repositioning tool. Electronic portal imaging with the use of fiducial markers was used to assess efficacy and accuracy. Patients undergoing radiation treatment for adenocarcinoma of the prostate were enrolled in a positioning study. Fifteen patients had five to six gold fiducial markers implanted in their prostate. These patients were positioned daily in a standard manner and then were repositioned every other day using an ultrasound-based correction system. Every fraction of a patients' treatment was imaged. This yielded 156 image pairs with and 119 pairs without repositioning available for analysis. This group of patients with markers had the following residual positions measured after the use of ultrasound repositioning. A mean error of −0.4 mm (LL), −2.6 mm (CC), and +2.5 mm (AP) with a standard deviation of 4.3, 5.4, and 5.7 mm. In two directions the improvements of treatment using the ultrasound correction were smaller than the precision of this experiment. They were no larger than 0.81 mm (LAT), and 0.95 mm (CC). In the AP direction a significant improvement was found of 1.6 mm. A highly significant correlation ($p<0.001$) was found between the residual errors in the cranio-caudal direction and the shifts performed on the basis of the ultrasound measurements (Spearman ranking $R=0.53$). We presented a method to objectively estimate improvements by a correction scheme. This method applied to ultrasound-based adjustment showed significant improvement in one direction and no measurable improvement in two other directions. © *2003 American Association of Physicists in Medicine.*
[DOI: 10.1118/1.1617354]

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doi:10.1016/S0360-3016(03)00633-3

CLINICAL INVESTIGATION **Prostate**

EVALUATION OF ULTRASOUND-BASED PROSTATE LOCALIZATION FOR IMAGE-GUIDED RADIOTHERAPY

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Purpose: To evaluate the use of the ultrasound-based BAT system for daily prostate alignment.
Materials and Methods: Prostate alignments using the BAT system were compared with alignments using radiographic images of implanted radiopaque markers. The latter alignments were used as a reference. The difference between the BAT and marker alignments represents the displacements that would remain if the alignments were done using ultrasonography. The inter-user variability of the contour alignment process was assessed.
Results: On the basis of the marker alignments, the initial displacement of the prostate in the AP, superoinferior, and lateral direction was −0.9 ± 3.9, 8.1 ± 5.8, and 0.2 ± 3.4 mm respectively. The directed differences between the BAT and marker alignments in the respective directions were 0.2 ± 3.7, 2.7 ± 3.8, and 1.6 ± 3.1 mm. The occurrence of displacements ≥5 mm was reduced by a factor of two in the AP direction after the BAT system was used. Among eight users, the average range of couch shifts due to contour alignment variability was 7, 7, and 5 mm in the antero-posterior (AP), superoinferior, and lateral direction, respectively.
Conclusions: In our study, the BAT alignments were systematically different from the marker alignments in the superoinferior, and lateral directions. The remaining random variability of the prostate position after the ultrasound-based alignment was similar to the initial variability. However, the occurrence of displacements ≥5 mm was reduced in the AP direction. The inter-user variation of the contour alignment process was significant.

Prostate cancer, Organ motion, Daily prostate localization.

- No one seems to argue that the process is good at eliminating large errors.

ultrasound-based alignment was similar to the initial variability. However, the occurrence of displacements ≥5 mm was reduced in the AP direction. The inter-user variation of the contour alignment process was significant.
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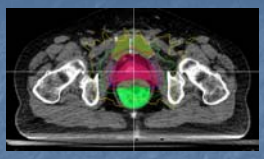
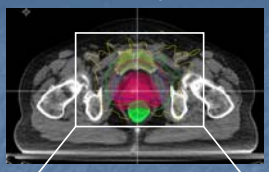
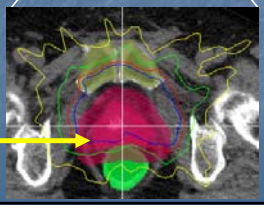
Treatment simulation



IMRT day 5

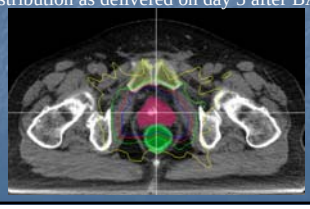




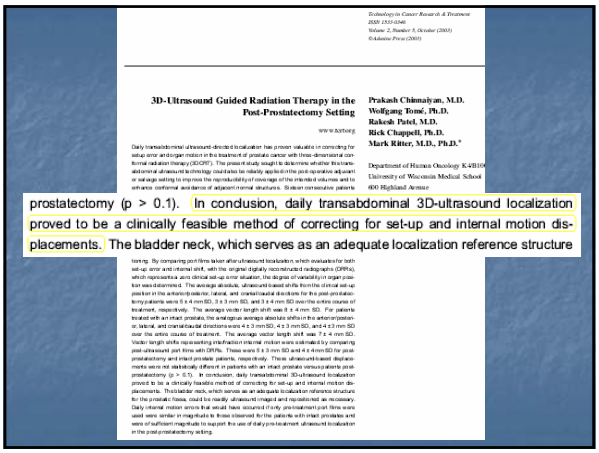
Marginal posterior GTV miss

Treatment simulation

Dose distribution as delivered on day 5 after BAT shift



Not all recent reports are critical…



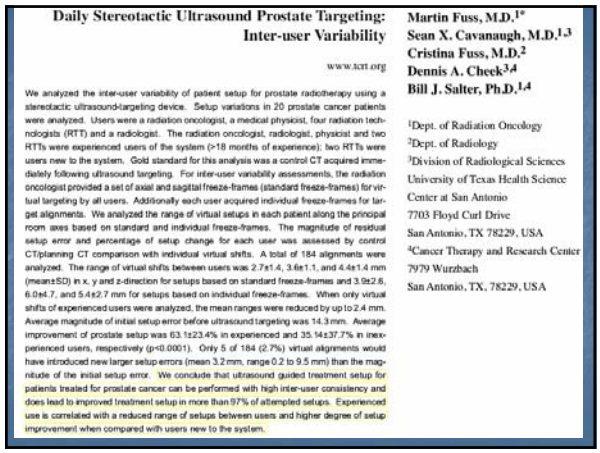
3D-Ultrasound Guided Radiation Therapy in the Post-Prostatectomy Setting

Prakash Chinnaiyan, M.D.
Wolfgang Tomé, Ph.D.
Rakesh Patel, M.D.
Rick Chappell, Ph.D.
Mark Ritter, M.D., Ph.D.*

www.tcrt.org

Daily transabdominal ultrasound-directed localization has proven valuable in correcting for set-up error and organ motion in the treatment of prostate cancer with three-dimensional conformal radiation therapy (3DCRT). The present study sought to determine whether this transabdominal ultrasound technology could also be reliably applied in the post-operative adjuvant or salvage setting to improve the reproducibility of coverage of the intended volumes and to enhance conformal avoidance of adjacent normal structures. Sixteen consecutive patients

prostatectomy ($p > 0.1$). In conclusion, daily transabdominal 3D-ultrasound localization proved to be a clinically feasible method of correcting for set-up and internal motion displacements. The bladder neck, which serves as an adequate localization reference structure



Daily Stereotactic Ultrasound Prostate Targeting: Inter-user Variability

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Sean X. Cavanaugh, M.D.[1,3]
Cristina Fuss, M.D.[2]
Dennis A. Cheek[3,4]
Bill J. Salter, Ph.D.[1,4]

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We analyzed the inter-user variability of patient setup for prostate radiotherapy using a stereotactic ultrasound-targeting device. Setup variations in 20 prostate cancer patients were analyzed. Users were a radiation oncologist, a medical physicist, four radiation technologists (RTT) and a radiologist. The radiation oncologist, radiologist, physicist and two RTTs were experienced users of the system (>18 months of experience); two RTTs were users new to the system. Gold standard for this analysis was a control CT acquired immediately following ultrasound targeting. For inter-user variability assessments, the radiation oncologist provided a set of axial and sagittal freeze-frames (standard freeze-frames) for virtual targeting by all users. Additionally each user acquired individual freeze-frames for target alignments. We analyzed the range of virtual setups in each patient along the principal room axes based on standard and individual freeze-frames. The magnitude of residual setup error and percentage of setup change for each user was assessed by control CT/planning CT comparison with individual virtual shifts. A total of 184 alignments were analyzed. The range of virtual shifts between users was 2.7±1.4, 3.6±1.1, and 4.4±1.4 mm (mean±SD) in x, y and z-direction for setups based on standard freeze-frames and 3.9±2.6, 6.0±4.7, and 5.4±2.7 mm for setups based on individual freeze-frames. When only virtual shifts of experienced users were analyzed, the mean ranges were reduced by up to 2.4 mm. Average magnitude of initial setup error before ultrasound targeting was 14.3 mm. Average improvement of prostate setup was 63.1±23.4% in experienced and 35.14±37.7% in inexperienced users, respectively ($p<0.0001$). Only 5 of 184 (2.7%) virtual alignments would have introduced new larger setup errors (mean 3.2 mm, range 0.2 to 9.5 mm) than the magnitude of the initial setup error. We conclude that ultrasound guided treatment setup for patients treated for prostate cancer can be performed with high inter-user consistency and does lead to improved treatment setup in more than 97% of attempted setups. Experienced use is correlated with a reduced range of setups between users and higher degree of setup improvement when compared with users new to the system.

Study design

Systematic QA study after 18 months of BAT use

Participants:

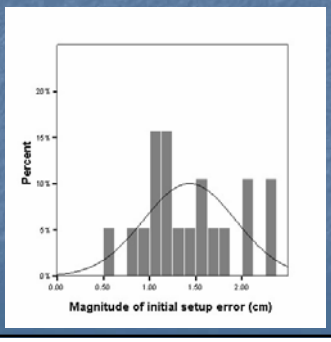
- 20 patients
- Radiation oncologist (1)
- Physicist (1)
- RT/T (4)
- Radiologist (1) (user gold standard)

Study design

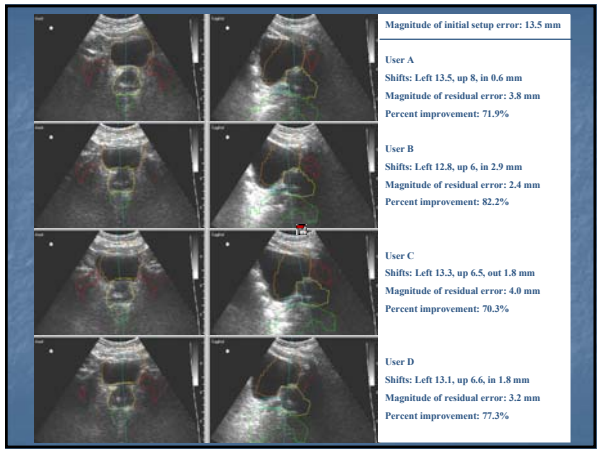
- BAT setup for use in the CT suite
- BAT calibrated to imaging plane of the CT
- Lasers aligned to skin marks
- BAT used to measure prostate misalignment
- Each user's indicated shifts recorded
- Patient CT immediately after BAT

Objective assessment

initial prostate displacement



mean 14.3 mm



We concluded…

- Average magnitude displacement of prostate prior to US alignment was 14.3 mm
- Average improvement of prostate setup was 63.1% for experienced users and 35.1% for inexperienced users
- Or, average "residual error" of 3mm in any given direction
- Only 5 of 184 alignments introduced new larger setup errors (mean=3.2 mm)
- US alignment can be performed with high interuser consistency, and led to improved treatment setup in more than 97% of attempted setups.
- Experienced use is correlated with a higher degree of setup improvement

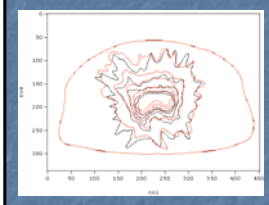
Perhaps more importantly, does improved spatial alignment translate into significant dosimetric improvement?

Study Design

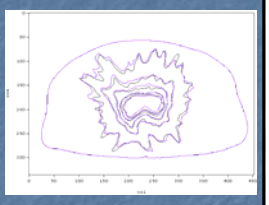
- 20 patients under BAT USG treatment
- Recorded daily x, y, z treatment shifts
- Recalculated the isodose distribution for each daily fraction to determine what would have happened without BAT alignment
- Summed each recalculated fraction to create a composite isodose distribution for each patient, representative of the dose distribution that would have been delivered with out BAT.

For BAT alignment

- Did not assume that BAT USG perfectly aligns the prostate
  (We just saw that it does not i.e. interuser variability)
- Performed a Monte Carlo simulation to randomly select x, y, z residual errors. Used data collected from Interuser variability study just described
- Recalculated the daily isodose distributions as for the No BAT scenario
- Summed the individual daily distributions to create a realistic composite distribution indicative of dose distribution achieved when BAT USG is used



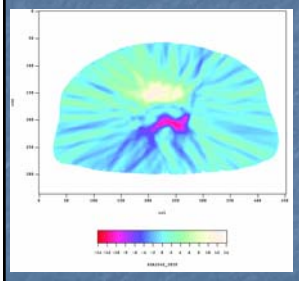
No US Alignment

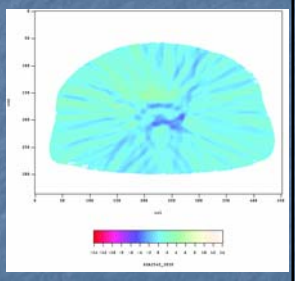


With BAT US Alignment

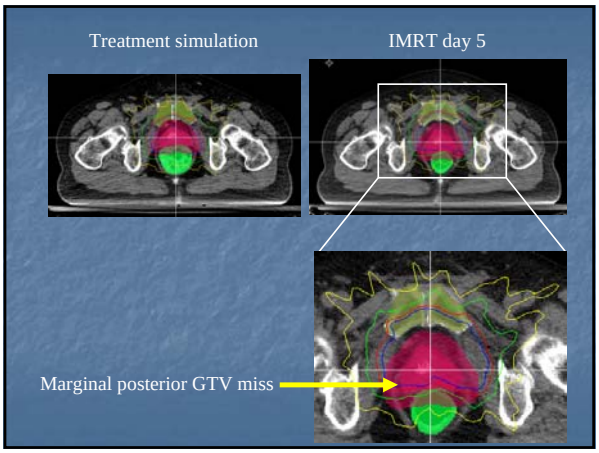
No BAT

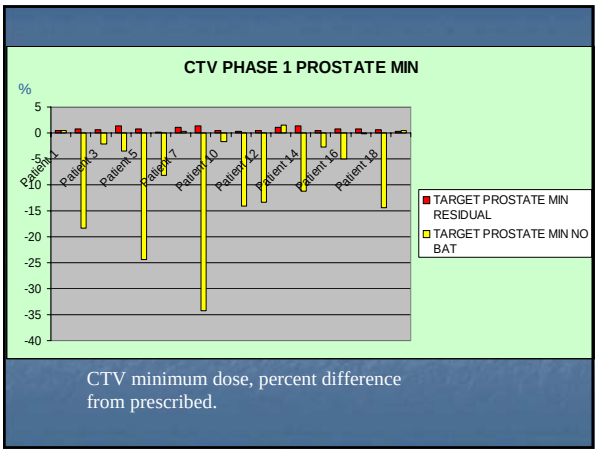
With BAT





What might cause such a systematic error?





CTV minimum dose, percent difference from prescribed.

In summary…

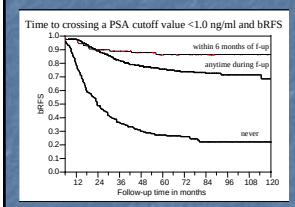
- In addition to improved spatial alignment of prostate target
- USG leads to significant improvement in delivered dose
- For conformal plans delivered without USG the minimum dose to the prostate CTV can be more than 30% lower than prescribed

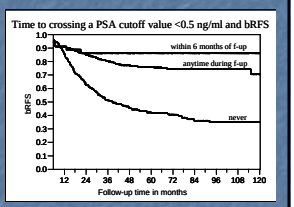
Does improved dosimetry lead to improved outcome?

- Improved prostate outcomes will take a long time to observe
- Are there possible early predictors?
- Funny you should ask ☺

Cavanaugh SX, Kupelian PA, Reddy C, Bradshaw P, Pollock BH, Fuss M. Early PSA kinetics following prostate cancer radiotherapy: prognostic value of a Time and PSA threshold model. Cancer 2004;101:96-105.

Cleveland Clinic Foundation long-term f-up database





All curves P<0.05

Early PSA Kinetics: Did We Dismiss Their Value Prematurely?
Conclusions

- Reaching or failing to reach the defined PSA thresholds (1.0, 0.5, 0.2) at 3 or 6 months was statistically predictive of the probability of long-term bRFS
- Patients reaching these low value nadirs of PSA within the first 3 to 6 months following treatment were shown to be significantly more likely to enjoy biochemical recurrent free survival

So, does USG increase the probability of reaching early PSA nadir of 1.0 or less?


PSA kinetics following IMRT for prostate cancer:
The impact of daily stereotactic ultrasound-based image-guided targeting

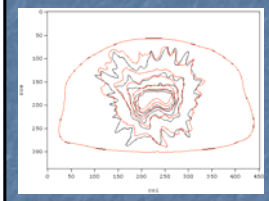
Conclusion: Between patients treated by IMRT without USG and those treated by IMRT with USG, those treated with USG reached early PSA nadirs significantly more often

Which seems to suggest...

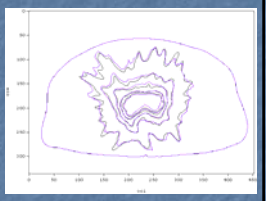
- That USG for prostate treatment may lead to better long term survival.

- And so we saw in our clinic, at least, that...
- If we trained our staff to use the USG system, we could achieve consistent and significant improvements in setup quality
- With mean "residual" errors (when compared to CT) of ~3mm in any given direction.

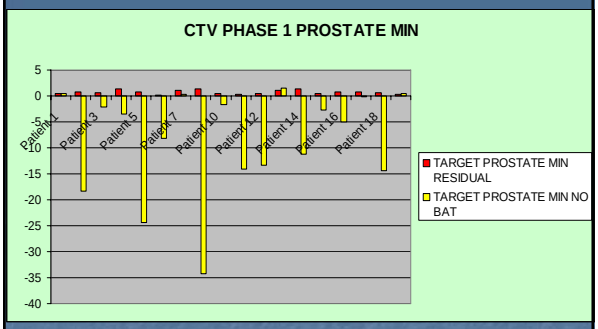
- We also saw that when we recomputed the composite dose distributions for our patients and included the residual error in target position characteristic of what our staff typically "left behind"
- The dose distributions were much better



No US Alignment



With BAT US Alignment



CTV minimum dose, percent difference from prescribed.

- And with regard to the most important question
- Namely, were we doing our patients any good?
- We saw that by using US IGRT for our prostate treatments
- We were increasing the likelihood that our patients would reach psa nadir more quickly
- Which, if you buy our analysis of the Cleveland Clinic long term follow up data, suggests that we may also have been improving their odds of (at least) long term bRFS.

In short,

- We concluded that USG for prostate patients in our clinic was a “good thing”.

Other sites for application of USG

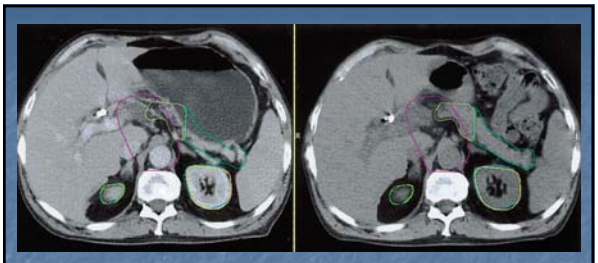
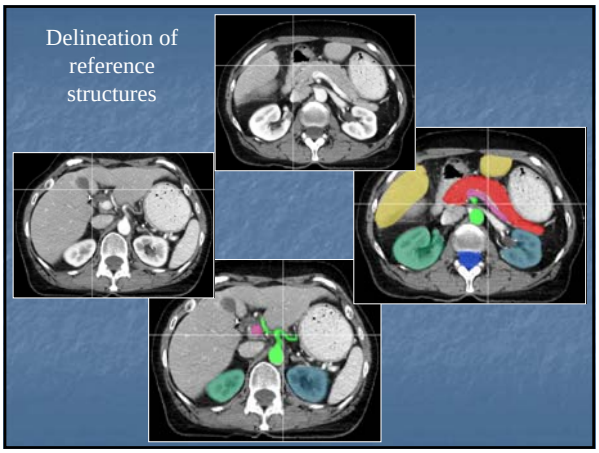
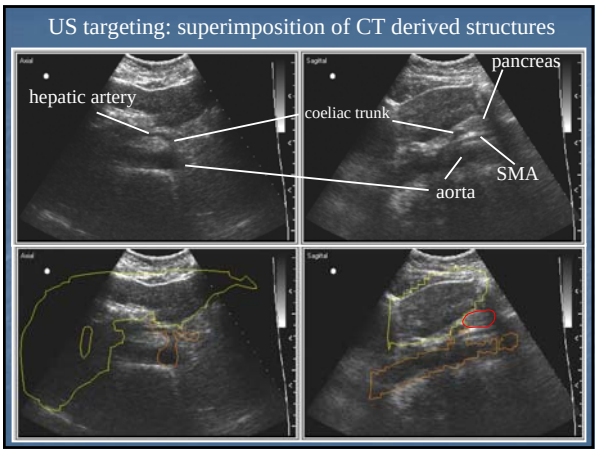


Figure 2. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue) and the target contour (violet) on the transverse non-contrast CT scan (right) project on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract) CT scan (left). The significant caudal translation of the pancreatic tail (light green) and parts of the pancreatic body (light yellow) owing to differential gastrointestinal distention are identified.

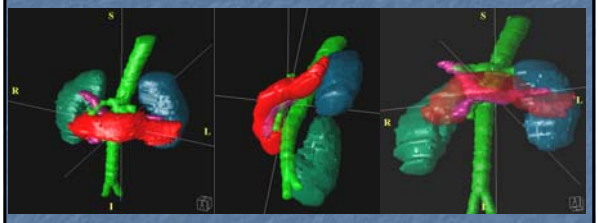
Delineation of reference structures



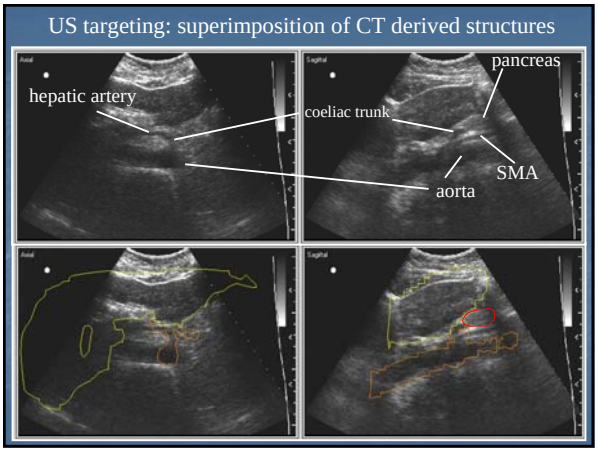
US targeting: superimposition of CT derived structures

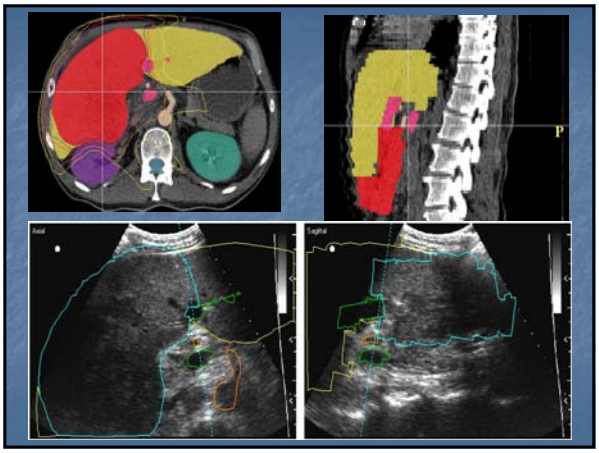


3D reconstruction



US targeting: superimposition of CT derived structures





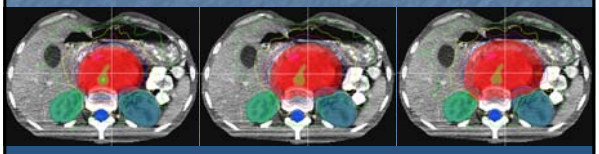
Correlation of BAT and CT positional control

- Assessed in 15 patients
  - BAT targeting in the CT simulation suite
  - Patient in treatment position
  - Comparison between planning CT sim and control CT
  - Target setup inaccuracy compared with BAT indicated shifts
- Mean magnitude of initial setup error
  - 13.95 mm (min 2.23, max 46.56 mm)
- Mean magnitude of residual setup error
  - 4.55 mm (min 1.92, max 12.82 mm)
  - mean improvement 45% (14/15 showed improvement)
    - Min -67% [1 case, initial 2.2 mm, residual 3.7 mm]
    - Max 95% [46.6 mm initial to 2.2 mm residual)

Does it matter?

Lets have a look at a clinical IMRT treatment plan

GTV 231 cm^3



Inoperable pancreatic cancer (impact of PTV safety margin on normal tissue at risk for toxicity)

PTV = CTV + 5 mm	PTV = CTV + 10 mm	PTV = CTV + 15 mm
volume 443 cm^3	volume 590 cm^3	volume 759 cm^3

Daily ultrasound-based image-guided targeting for radiotherapy of upper abdominal malignancies.

Martin Fuss, M.D.,† Bill J. Salter, Ph.D.,†º
Sean X. Cavanaugh, M.D.,†* Cristina Fuss, M.D.,§ Amir Sadeghi, Ph.D.,º
Clifton D. Fuller,* Ardow Ameduri, M.D.,º James M. Hevezi, Ph.D.,º
Terence S. Herman, M.D.,† Charles R. Thomas Jr., M.D.,†
Int J Radiat Oncol Biol Phys. 2004 Jul 15;59(4):1245-56.

External beam radiation therapy for hepatocellular carcinoma: potential of intensity modulated and image guided radiation therapy.

Martin Fuss, M.D.,† Bill J. Salter, Ph.D.,†º
Terence S. Herman, M.D.,† Charles R. Thomas Jr., M.D.,†
Gastroenterology. 2004 Nov; 127(5 Suppl 1):S206-17. Review.

- So, In-Room USG can be applied to important targets other than prostate
- With significant improvement in daily setup accuracy
- Leading to significant reduction of the amount of healthy tissue treated
- With a subsequent (assumed) reduction of NT complication OR
- The ability to dose escalate.

Learning objectives

- Rationale for In-Room Guidance
- Rationale for US In-Room Guidance
- The USG Process
- Key components of the process
- QA considerations
- Dosimetric implications
- Outcome implications
- Other sites of application

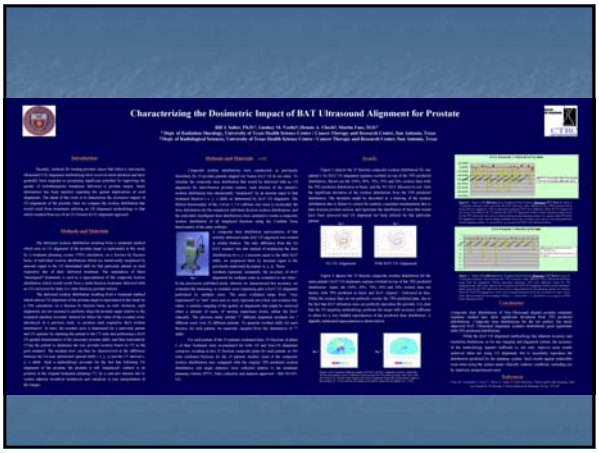
In conclusion

- In room image guidance is needed because the prostate and/or abdominal structures such as pancreas move.
- US in-room guidance can provide a non-invasive, real-time assessment of both target and critical structure alignment immediately prior to treatment.
- The method does not require deposition of ionizing radiation dose and is capable of depicting the intra fraction component of target and critical structure motion for prostate and also for other important sites such as pancreas and liver.

In summary

- The clinical process employs various key components, which must be appropriately commissioned and QA'd
- Not the least of which is the individual users of the system.
- Through appropriate attention to the underlying details of the process, an in-room US Guided approach can be extremely effective in reducing the dosimetric errors associated with target and critical structure interfractional motion for important sights such as prostate, pancreas and liver.
- The methods and resources necessary to implement such an approach are modest, and achievable by "typical" community based centers.

Does improved spatial alignment translate into significant dosimetric improvement?



Study Design

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- Recorded daily x, y, z treatment shifts
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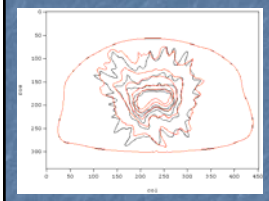
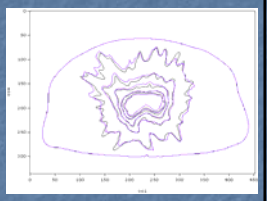
For BAT alignment

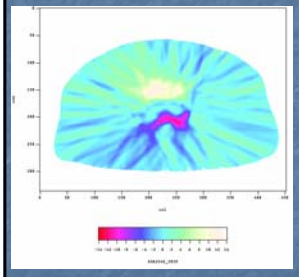
- Did not assume that BAT USG perfectly aligns the prostate
  (We just saw that it does not i.e. interuser variability)
- Performed a Monte Carlo simulation to randomly select x, y, z residual errors. Used data collected from Interuser variability study (TCRT)
- Recalculated the daily isodose distributions as for the No BAT scenario
- Summed the individual daily distributions to create a realistic composite distribution indicative of dose distribution achieved when BAT USG is used

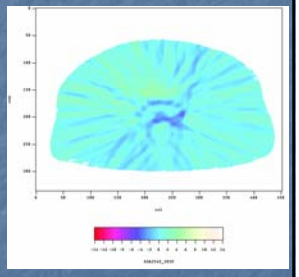


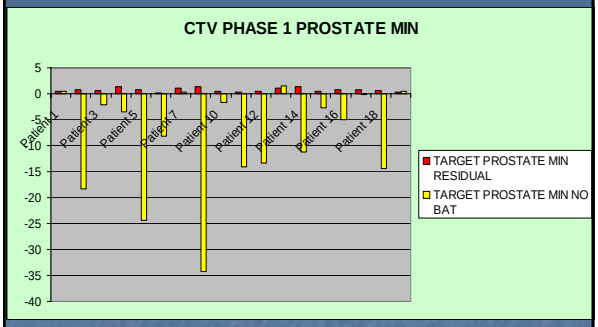
No US Alignment



With BAT US Alignment







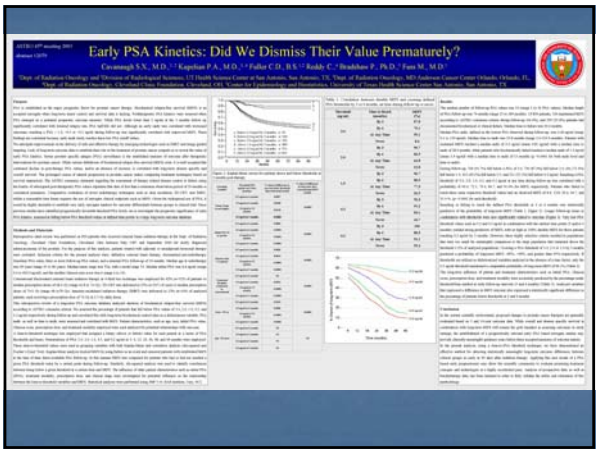
CTV minimum dose, percent difference from prescribed.

In summary...

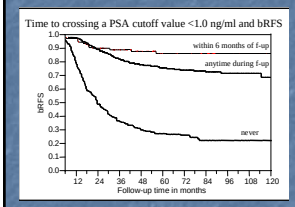
- In addition to improved spatial alignment of prostate target
- USG leads to significant improvement in delivered dose
- Without USG the minimum dose to the prostate CTV can be more than 30% lower than prescribed

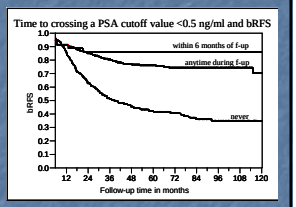
Does improved dosimetry lead to improved outcome?

- Improved prostate outcomes will take a long time to observe
- Are there possible early predictors?
- Funny you should ask ☺



Cleveland Clinic Foundation long-term f-up database





Cavanaugh SX, Kupelian P, Fuss M unpublished

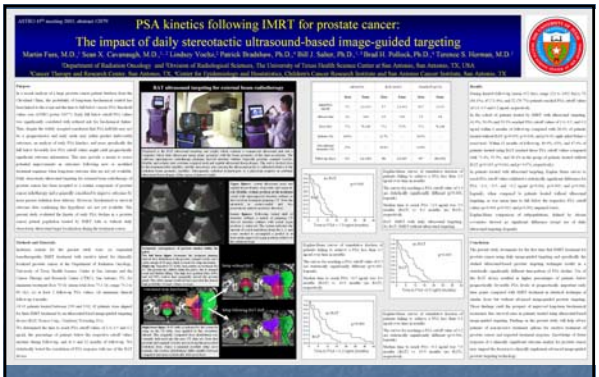
All curves P<0.05

Early PSA Kinetics: Did We Dismiss Their Value Prematurely?
Conclusions

- Reaching or failing to reach the defined PSA thresholds (1.0, 0.5, 0.2) at 3 or 6 months was statistically predictive of the probability of long-term bRFS
- Patients reaching these low value nadirs of PSA within the first 3 to 6 months following treatment were shown to be significantly more likely to enjoy biochemical recurrent free survival

So, does USG increase the probability of reaching early PSA nadir of 1.0 or less?

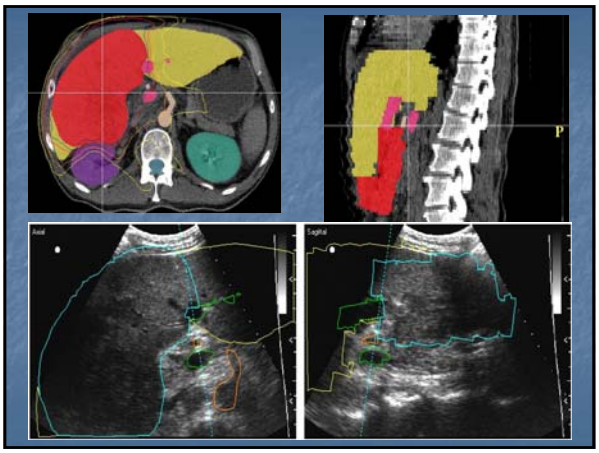
- Funny you should ask again ☺

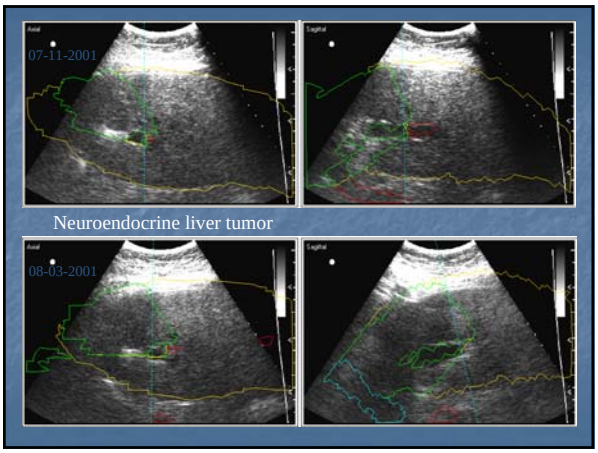


Conclusion: Between patients treated by IMRT without USG and those treated by IMRT with USG, those treated with USG reached early PSA nadirs significantly more often

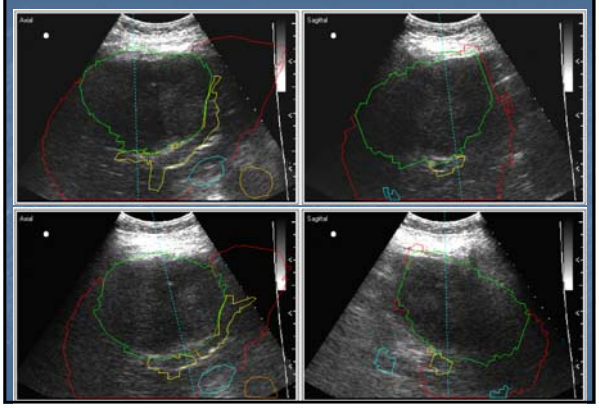
Which seems to suggest...

- That USG for prostate treatment may lead to better long term survival.





Liver metastasis breast cancer



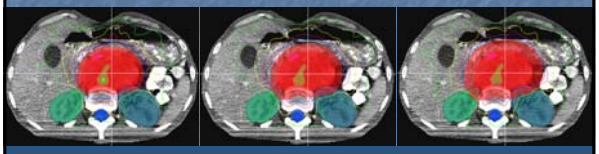
Correlation of BAT and CT positional control

- Assessed in 15 patients
  - BAT targeting in the CT simulation suite
  - Patient in treatment position
  - Comparison between planning CT sim and control CT
  - Target setup inaccuracy compared with BAT indicated shifts
- Mean magnitude of initial setup error
  - 13.95 mm (min 2.23, max 46.56 mm)
- Mean magnitude of residual setup error
  - 4.55 mm (min 1.92, max 12.82 mm)
  - mean improvement 45% (14/15 showed improvement)
    - Min -67% [1 case, initial 2.2 mm, residual 3.7 mm]
    - Max 95% [46.6 mm initial to 2.2 mm residual)

Does it matter?

Lets have a look at a clinical IMRT treatment plan

GTV 231 cm³



Inoperable pancreatic cancer (impact of PTV safety margin on normal tissue at risk for toxicity)

PTV = CTV + 5 mm	PTV = CTV + 10 mm	PTV = CTV + 15 mm
volume 443 cm³	volume 590 cm³	volume 759 cm³

- BAT alignment for abdominal target volumes is feasible
- Direct target alignment or alignment in relation to vascular guidance structures is feasible
- significant reduction of setup errors

- A considerable proportion of daily setups shows setup errors larger than 10 and 15 mm
- This indicates the need for advanced targeting on a daily basis

Use of ultrasound targeting allows for reduced safety margins and enables normal tissue dose reduction or dose escalation

- Daily stereotactic ultrasound targeting enables improved target volume setup in abdominal tumor radiotherapy
- Added efforts for physician, physicist (QA) and RTT
- Technique can be implemented into clinical routine
  - On 4/4/03, 5 cases under treatment at UTHSCSA/CTRC

SMA

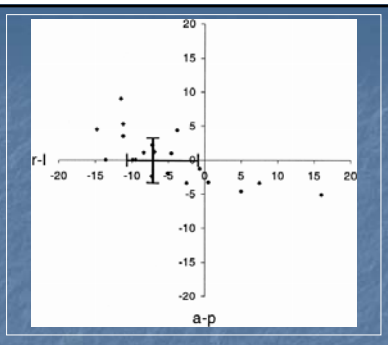
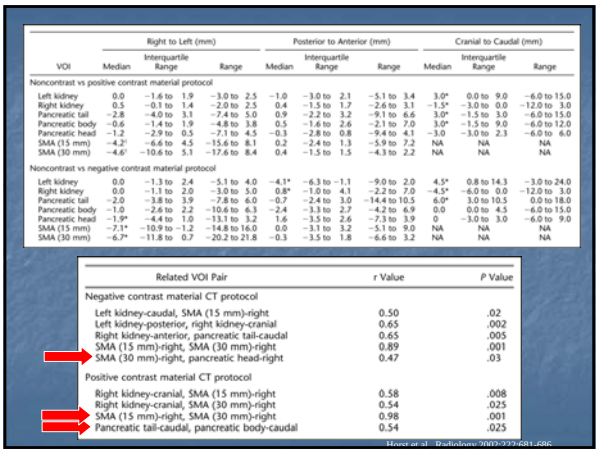


Figure 1. Graph depicts the antero-posterior *(a-p)* and right-left *(r-l)* translations of the SMA at 15 mm from origin in the negative contrast material protocol for each patient. The intersection of the thick solid lines indicates the median translations and their lengths indicate interquartile ranges (q25-q75) in the two dimensions.

Horst et al., Radiology 2002;222:681-686



VOI	Right to Left (mm) Median	Interquartile Range	Range	Posterior to Anterior (mm) Median	Interquartile Range	Range	Cranial to Caudal (mm) Median	Interquartile Range	Range
Noncontrast vs positive contrast material protocol									
Left kidney	0.0	−1.6 to 1.9	−3.0 to 2.5	−1.0	−3.0 to 2.1	−5.1 to 3.4	3.0*	0.0 to 9.0	−6.0 to 15.0
Right kidney	0.5	−0.1 to 1.4	−2.0 to 2.5	0.4	−1.5 to 1.7	−2.6 to 3.1	−1.5*	−3.0 to 0.0	−12.0 to 3.0
Pancreatic tail	−2.8	−4.0 to 3.1	−7.4 to 5.0	0.9	−2.2 to 3.2	−9.1 to 6.6	3.0*	−1.5 to 3.0	−6.0 to 15.0
Pancreatic body	−0.6	−1.4 to 1.9	−4.8 to 3.8	0.5	−1.6 to 2.6	−2.1 to 7.0	3.0*	−1.5 to 9.0	−6.0 to 12.0
Pancreatic head	−1.2	−2.9 to 0.5	−7.1 to 4.5	−0.3	−2.8 to 0.8	−9.4 to 4.1	−3.0	−3.0 to 2.3	−6.0 to 6.0
SMA (15 mm)	−4.2†	−6.6 to 4.5	−15.6 to 8.1	0.2	−2.4 to 1.3	−5.9 to 7.2	NA	NA	NA
SMA (30 mm)	−4.6†	−10.6 to 5.1	−17.6 to 8.4	0.4	−1.5 to 1.5	−4.3 to 2.2	NA	NA	NA
Noncontrast vs negative contrast material protocol									
Left kidney	0.0	−1.3 to 2.4	−5.1 to 4.0	−4.1*	−6.3 to −1.1	−9.0 to 2.0	4.5*	0.8 to 14.3	−3.0 to 24.0
Right kidney	0.0	−1.1 to 2.0	−3.0 to 5.0	0.8*	−1.0 to 4.1	−2.2 to 7.0	−4.5*	−6.0 to 0.0	−12.0 to 3.0
Pancreatic tail	−2.0	−3.8 to 3.9	−7.8 to 6.0	−0.7	−2.4 to 3.0	−14.4 to 10.5	6.0*	3.0 to 10.5	0.0 to 18.0
Pancreatic body	−1.0	−2.6 to 2.2	−10.6 to 6.3	−2.4	−3.3 to 2.7	−4.2 to 6.9	0.0	0.0 to 4.5	−6.0 to 15.0
Pancreatic head	−1.9*	−4.4 to 1.0	−13.1 to 3.2	1.6	−3.5 to 2.6	−7.3 to 3.9	0	−3.0 to 3.0	−6.0 to 9.0
SMA (15 mm)	−7.1*	−10.9 to −1.2	−14.8 to 16.0	0.0	−3.1 to 3.2	−5.1 to 9.0	NA	NA	NA
SMA (30 mm)	−6.7*	−11.8 to 0.7	−20.2 to 21.8	−0.3	−3.5 to 1.8	−6.6 to 3.2	NA	NA	NA

Related VOI Pair	r Value	P Value
Negative contrast material CT protocol		
Left kidney-caudal, SMA (15 mm)-right	0.50	.02
Left kidney-posterior, right kidney-cranial	0.65	.002
Right kidney-anterior, pancreatic tail-caudal	0.65	.005
SMA (15 mm)-right, SMA (30 mm)-right	0.89	.001
SMA (30 mm)-right, pancreatic head-right	0.47	.03
Positive contrast material CT protocol		
Right kidney-cranial, SMA (15 mm)-right	0.58	.008
Right kidney-cranial, SMA (30 mm)-right	0.54	.025
SMA (15 mm)-right, SMA (30 mm)-right	0.98	.001
Pancreatic tail-caudal, pancreatic body-caudal	0.54	.025

Hoyer et al • Radiology 2000;223:691-696

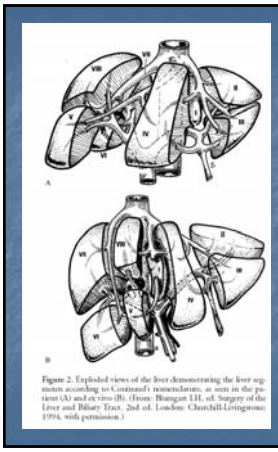


Figure 2. Exploded views of the liver demonstrating the liver segments according to Couinaud's nomenclature, as seen in the patient (A) and ex vivo (B). (From: Blumgart LH, ed. Surgery of the Liver and Biliary Tract. 2nd ed. London: Churchill-Livingstone; 1994, with permission.)

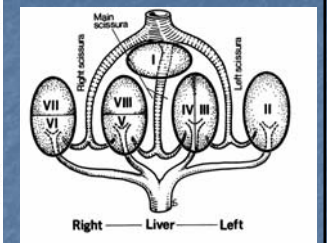


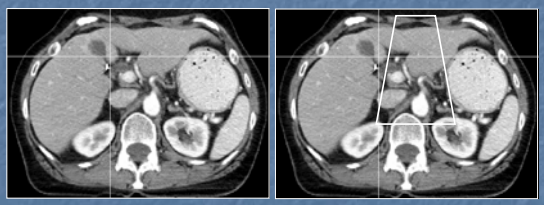
Figure 1. Segmental organization of the liver. The hepatic veins reside in the portal scissurae, which divide the liver into four sectors. Each sector is composed of one or more anatomic segments. The right hemiliver consists of segments V, VI, VII, and VIII. The left hemiliver consists of segments II, III, and IV.

Other abdominal target volumes

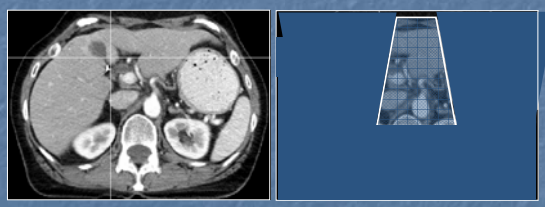
- Pancreas
  - Difficult to visualize in ultrasound
  - Individually close organ relation to major named vessels
- Neuroblastoma
  - Vertebral bodies are part of the CTV/PTV
  - Often close relation to abdominal/retroperitoneal vessels
  - Most often close relation with one kidney/liver

Stereotactic ultrasound targeting for abdominal target volumes:
Potential limitations

US image window



US image window



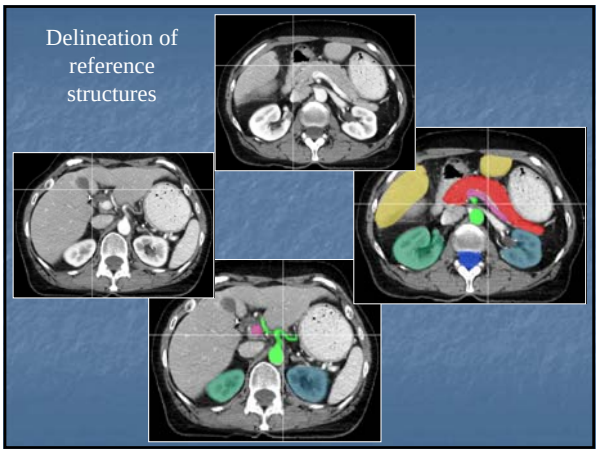
Limited field of view

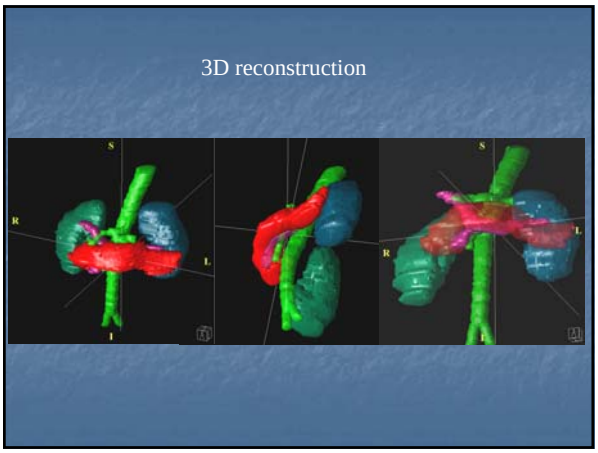
Limited ultrasound penetration

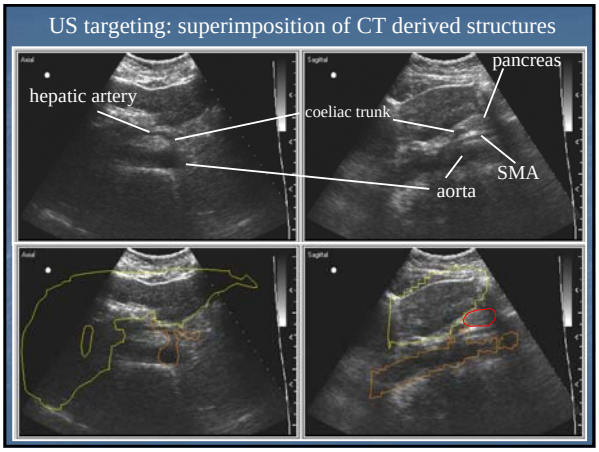
Limited ultrasound field of view

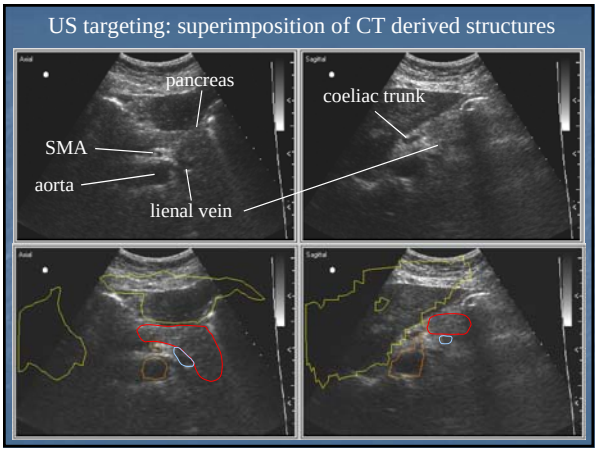
- Organ outlines may be helpful
  - Caudate lobe of the liver
  - Kidney outline
- However, organs are only partially represented
- Vasculature is well represented in ultrasound

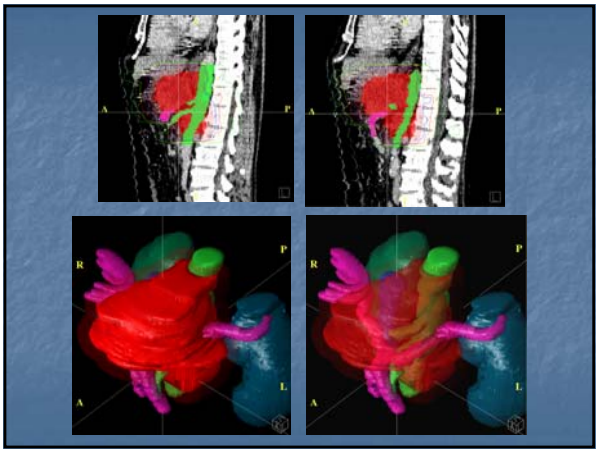
What is the value of using vasculature or other guidance structures for radiotherapy targeting in the upper abdomen?

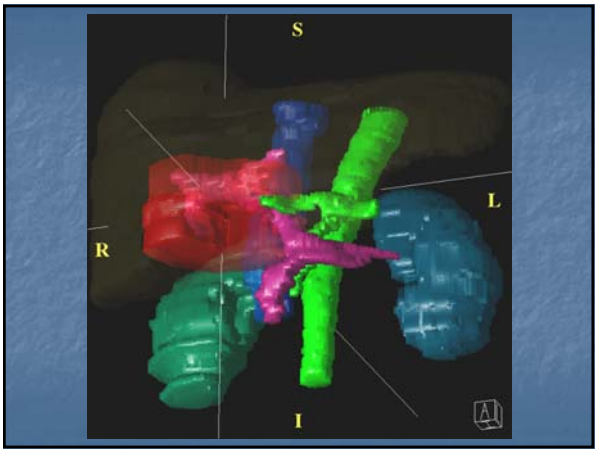

Delineation of reference structures


3D reconstruction


US targeting: superimposition of CT derived structures
hepatic artery
coeliac trunk
pancreas
SMA
aorta


US targeting: superimposition of CT derived structures
pancreas
coeliac trunk
SMA
aorta
lienal vein

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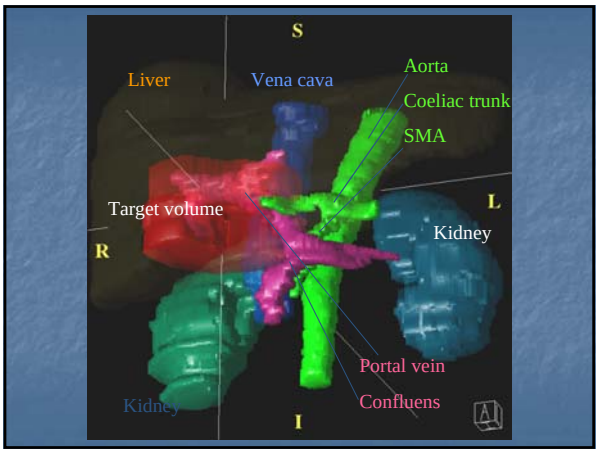
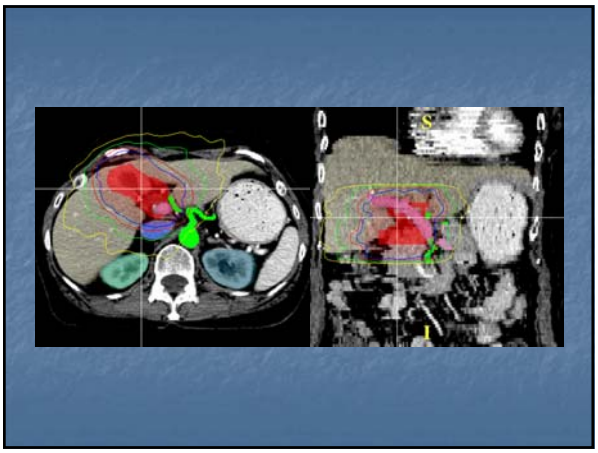
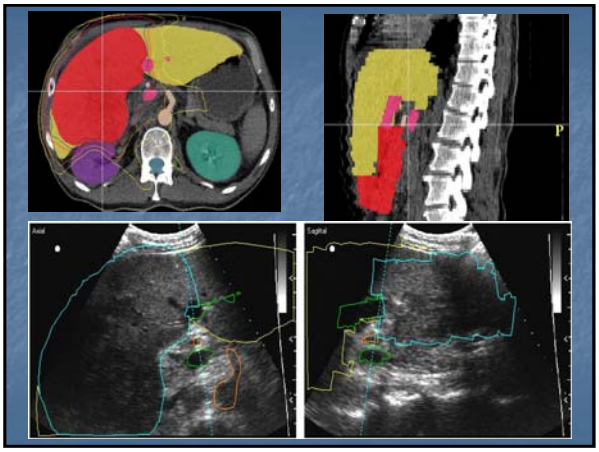
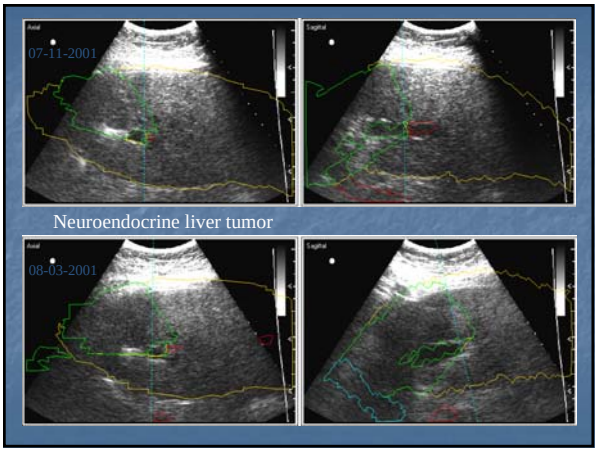
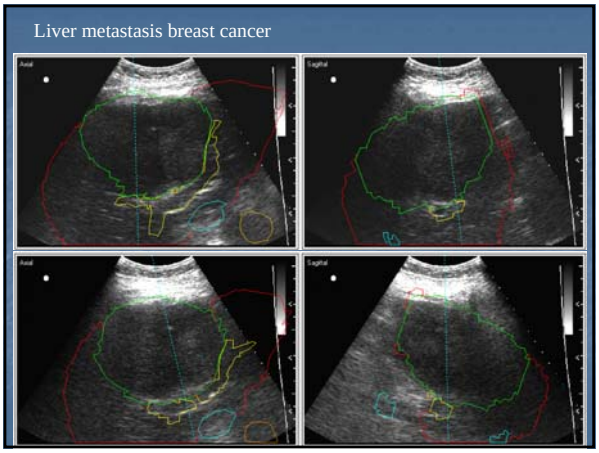








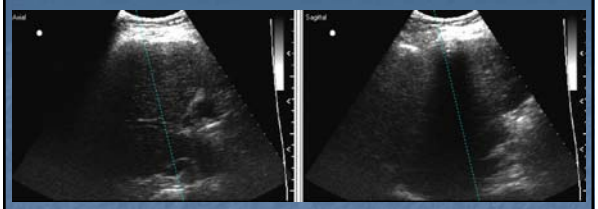


Treatment planning

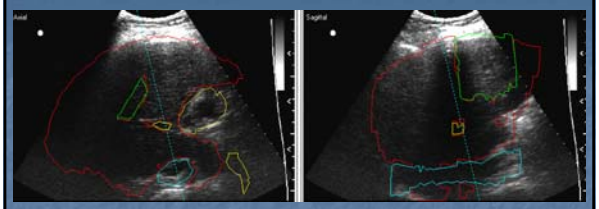
- 3-phase contrast CT
- Ultrasound examination
- Target and organ at risk delineation
- Delineation of major vessels
  portal vein, hepatic artery, IVC, bile ducts

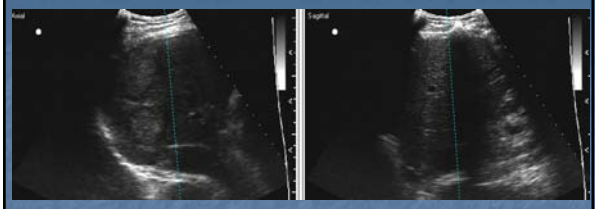
Treatment planning

- Inverse IMRT treatment planning (Corvus, Nomos)
- Creation of a BAT study (export of structure outlines into the BAT – current limit 5 structures)

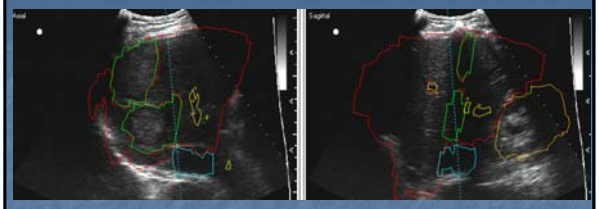


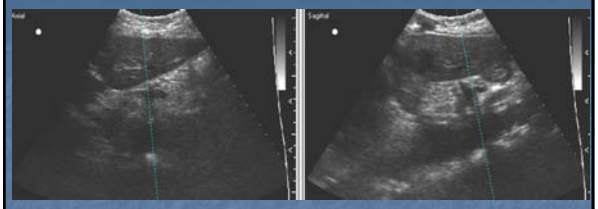
Hepatocellular Carcinoma



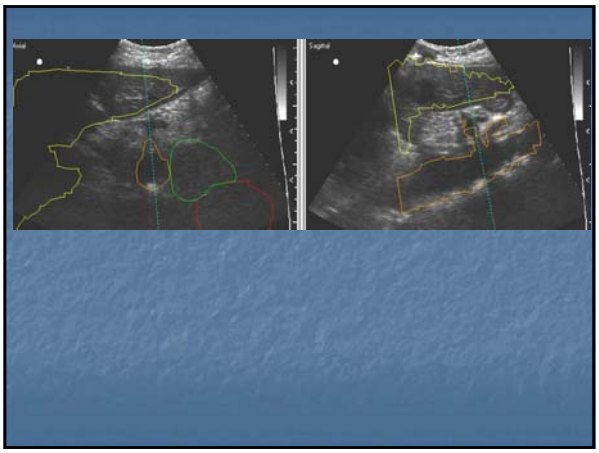


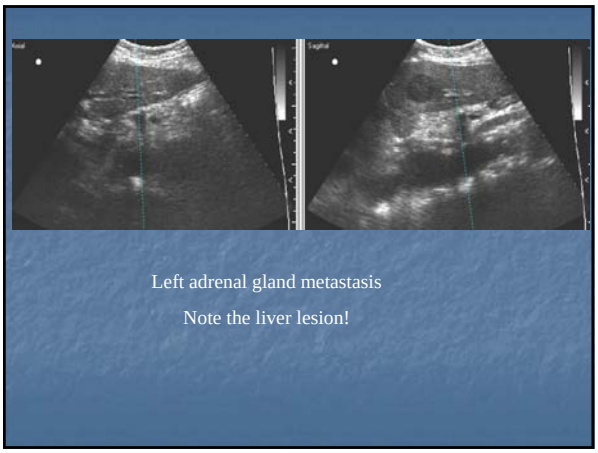
Liver Metastases





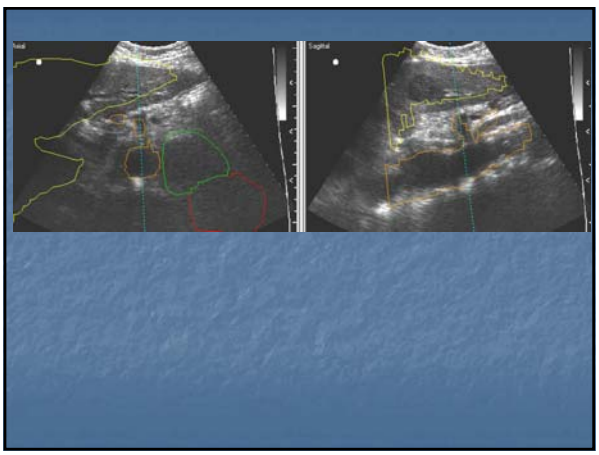
Left adrenal gland metastasis





Left adrenal gland metastasis

Note the liver lesion!

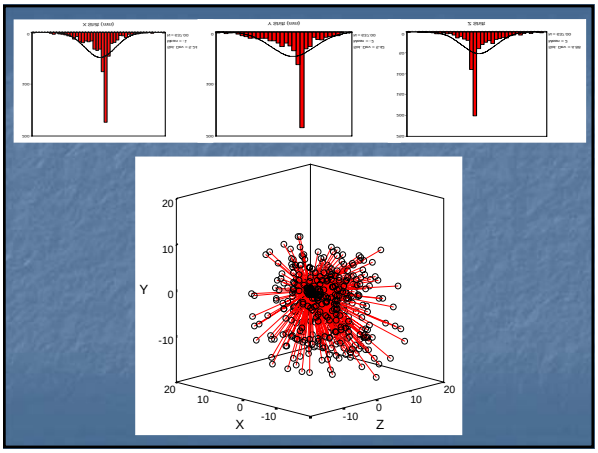


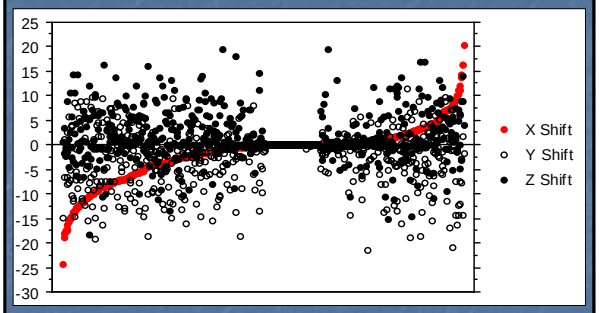
Clinical experience

- Since 11/2000
  - BAT had been implemented for prostate cancer IMRT in 9/2000
- 52 patients
  - HCC (10)
  - Liver metastases (10)
  - Cholangio Ca (8)
  - Pancreatic Ca (16)
  - Neuroblastoma (4)
  - Other (4)

BAT executed shifts

- X-axis mean 3.2±4.0 mm (95% CI 11.2 mm)
- Y-axis mean 4.1±4.7 mm (95% CI 13.5 mm)
- Z-axis mean 3.2±4.3 mm (95% CI 11.8 mm)
- 3D magnitude vector of shift
  mean 7.6±7.1 mm (95% CI 21.8 mm)
- Test against 0 hypothesis
  P<0.0001 (all axes and the magnitude vector)





	X-Axis	Y-Axis	Z-Axis	Any Axis	3D Vector
≥10 mm	18/31 Patients	13/31 Patients	17/31 Patients	22/31 Patients	24/31 Patients 77.4%
	88/637 Alignments	69/637 Alignments	52/637 Alignments	161/637 Alignments	223/637 Alignments 35%
≥15 mm	6/31 Patients	5/31 Patients	6/31 Patients	12/31 Patients	16/31 Patients 51.6%
	13/637 Alignments	14/637 Alignments	9/637 Alignments	44/637 Alignments	91/637 Alignments 14.3%
≥20 mm	2/31 Patients	2/31 Patients	1/31 Patients	5/31 Patients	9/31 Patients 29%
	2/637 Alignments	2/637 Alignments	1/637 Alignments	6/637 Alignments	22/637 Alignments 3.5%

Correlation of BAT and CT positional control

- Assessed in 15 patients
  - BAT targeting in the CT simulation suite
  - Patient in treatment position
  - Comparison between planning CT sim and control CT
  - Target setup inaccuracy compared with BAT indicated shifts
- Mean magnitude of initial setup error
  - 13.95 mm (min 2.23, max 46.56 mm)
- Mean magnitude of residual setup error
  - 4.55 mm (min 1.92, max 12.82 mm)
  - mean improvement 45% (14/15 showed improvement)
    - Min -67% [1 case, initial 2.2 mm, residual 3.7 mm]
    - Max 95% [46.6 mm initial to 2.2 mm residual)

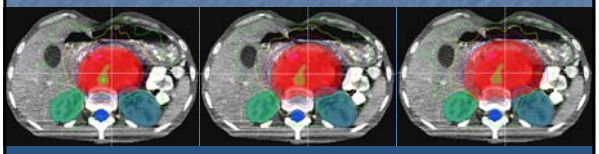
Preliminary conclusion

- Daily stereotactic ultrasound targeting enables improved target volume setup in abdominal tumor radiotherapy
- Added efforts for physician, physicist (QA) and RTT
- Technique can be implemented into clinical routine
  - On 4/4/03, 5 cases under treatment at UTHSCSA/CTRC

Does it matter?

Lets have a look at a clinical IMRT treatment plan

GTV 231 cm^3



Inoperable pancreatic cancer (impact of PTV safety margin on normal tissue at risk for toxicity)

PTV = CTV + 5 mm	PTV = CTV + 10 mm	PTV = CTV + 15 mm
volume 443 cm^3	volume 590 cm^3	volume 759 cm^3

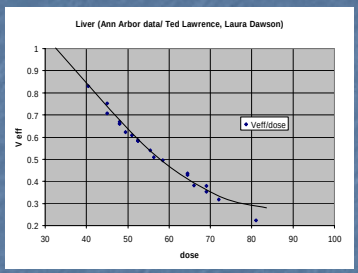
Pancreatic Cancer

- Radiation dose limited by bowel radiation tolerance
- Combined chemo-radiation or tumor sensitization might cause more toxicity
- Radiation dose escalation promising with regard to local control – but not survival (Ceha et al., Cancer, 89:2000)
- Reduced normal tissue exposure may result in better quality-of-life
  - Currently assessed at UTHSCSA

Liver Cancer

- Radiation dose limited by risk for veno-occlusive disease
- Combined chemo-radiation might cause more toxicity
- Radiation dose escalation promising with regard to local control and survival (Dawson et al., IJROBP 48:2000)
- Ann Arbor working group has established a dose-volume relationship for normal liver radiation tolerance
- Reduced normal tissue exposure may result in better quality-of-life
  - Currently assessed at UTHSCSA

Normal liver radiation tolerance



If the volume of normal liver tissue exposed can be reduced, significant dose escalation is enabled

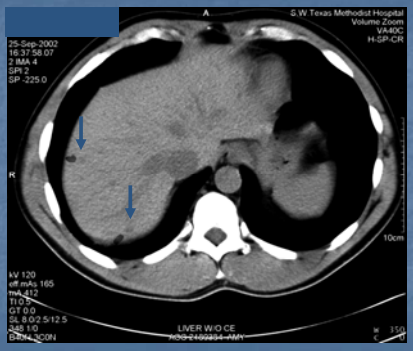
- BAT alignment for abdominal target volumes is feasible
- Direct target alignment or alignment in relation to vascular guidance structures is feasible
- significant reduction of setup errors

- A considerable proportion of daily setups shows setup errors larger than 10 and 15 mm
- This indicates the need for advanced targeting on a daily basis

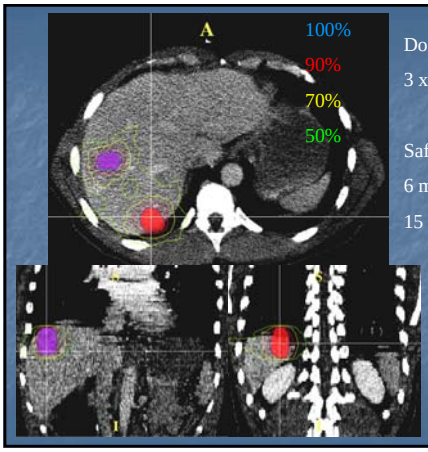
Use of ultrasound targeting allows for reduced safety margins and enables normal tissue dose reduction or dose escalation

Ultrasound targeting may be valuable for hypofractionated treatments or extracranial radioablation procedures

Hepatic metastases – colorectal cancer



Metastases colorectal cancer



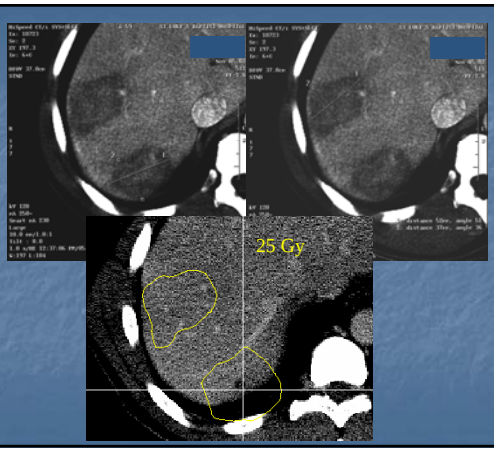
Dose prescription:

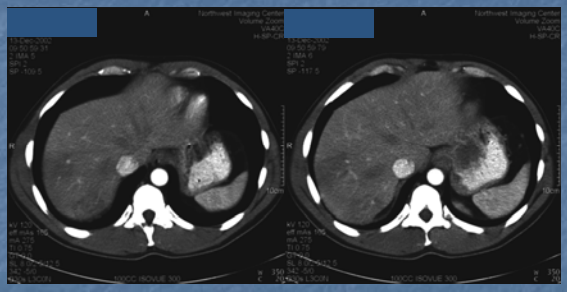
3 x 12 Gy, TD 36 Gy

Safety Margins;

6 mm lateral

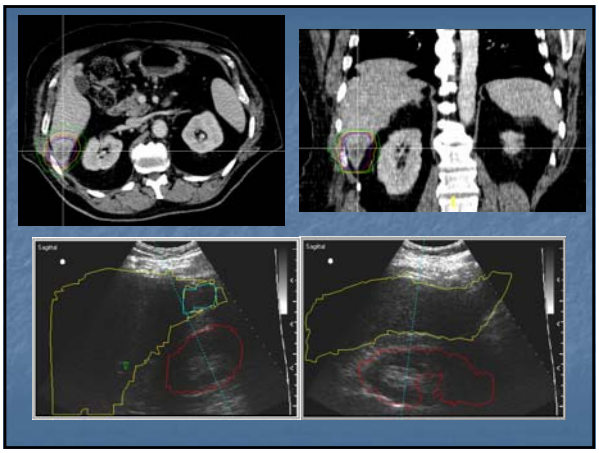
15 mm cranio-caudal

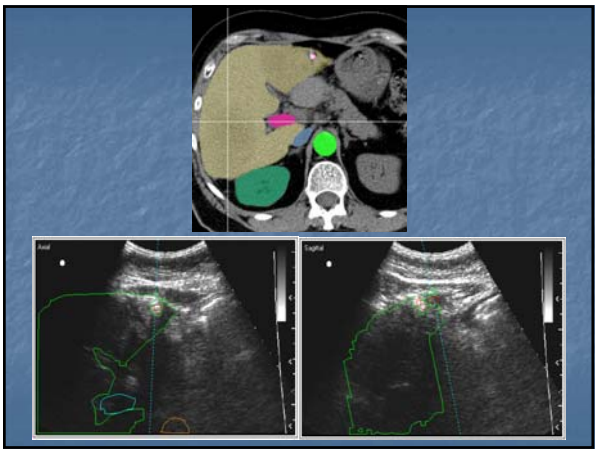


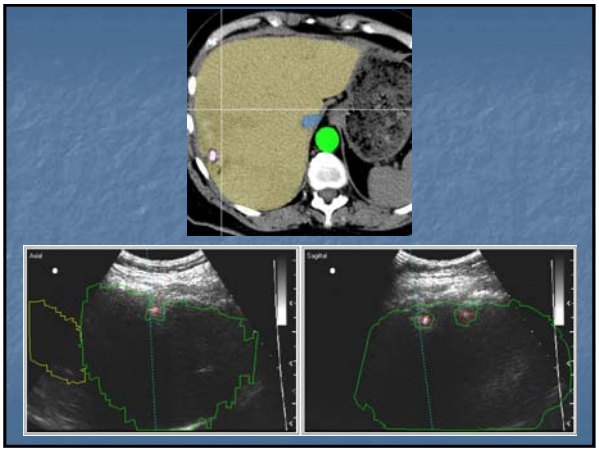


Potential challenges in ECRA of liver lesions

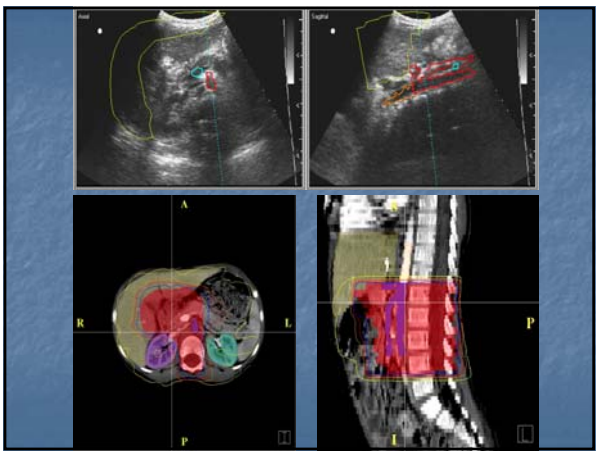
- Patient and target setup
  - Most important factor
  - Largest variation
- Most often refers to bony landmarks
- Breathing motion and organ displacement due to differential breathing pattern and bowel filling will occur
  - Potential solutions:
    - Gating devices
    - Image-guided targeting
    - Anesthesia, iatrogene pneumothorax, high frequency Jet ventilation

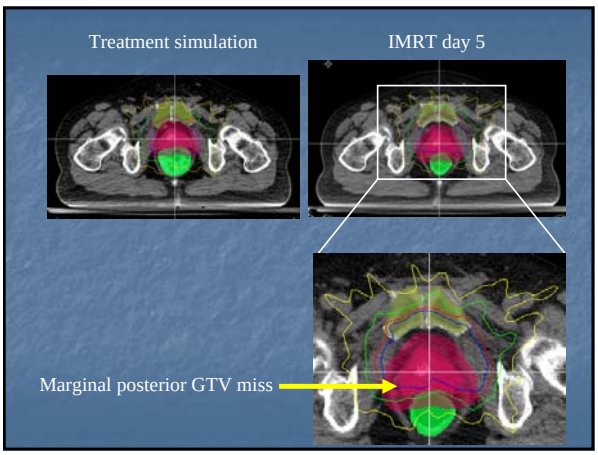




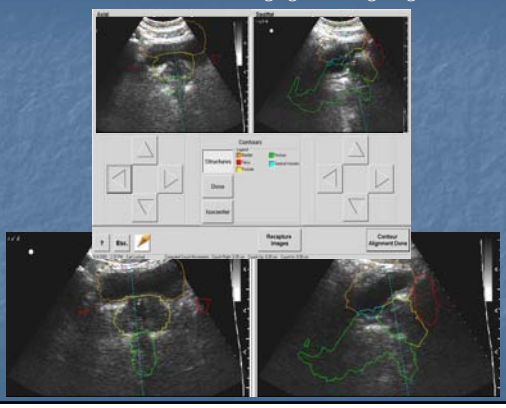


- Bill J. Salter, PhD
- Amir Sadeghi, PhD
- Sean Cavanaugh, MD, PhDc
- Irma Diaz, CMD
- Lynn Warcola, RT(R)(T)
- Anita Sands, RT(T)
- Sain Buxton, RT(R)(T)
- Art Escobedo, RT(R)
- Loretta Medina, RT(T)



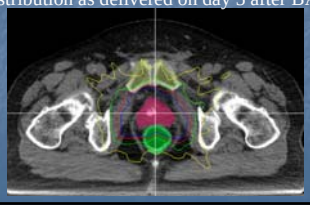


Ultrasound-based image guided targeting



Treatment simulation

Dose distribution as delivered on day 5 after BAT shift



Rationale to use the BAT

- Setup to skin marks may not indicate target position due to relative target movement to bony structures and skin
- Problem: tight safety margins and conformal dose distributions might lead to target miss

Why use the BAT?

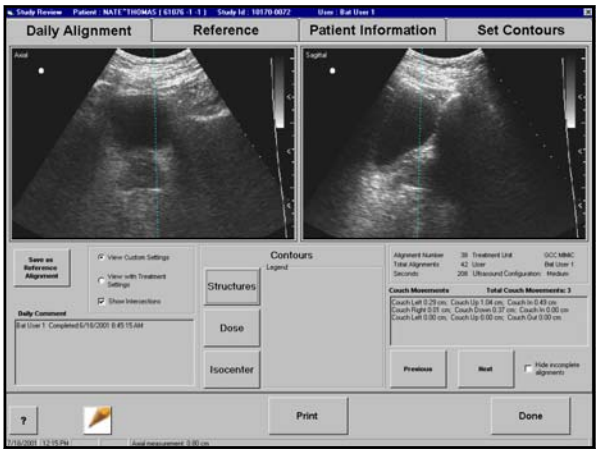
- The BAT can visualize the target directly and give positional information about target and organs at risk
- Target structures move on a day to day basis. The BAT is an accurate way to make daily adjustments in couch position for those movements
- Ideally it allows for a decrease in the planning target volume (PTV) and keeps the radiated area more closely approximated to the clinical target volume

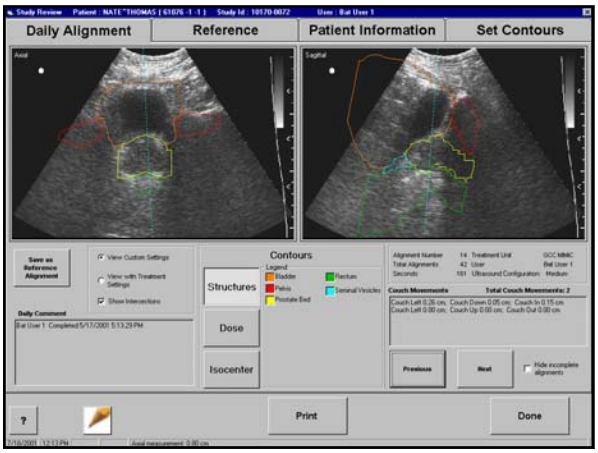
BAT alignment

- Patient is aligned according to skinmarks and room lasers
- An ultrasound image of the patient is taken with the patient on the treatment couch (in treatment position) immediately before XRT
- Axial and sagittal images are taken

Ultrasound image & target

- The previous outlined target and organs at risk (derived from treatment planning CT) are super-imposed on the BAT's ultrasound image
- The system allows for virtual shifts of the CT volumes until a best match between US and CT is accomplished.
- The system indicates the required couch shifts.



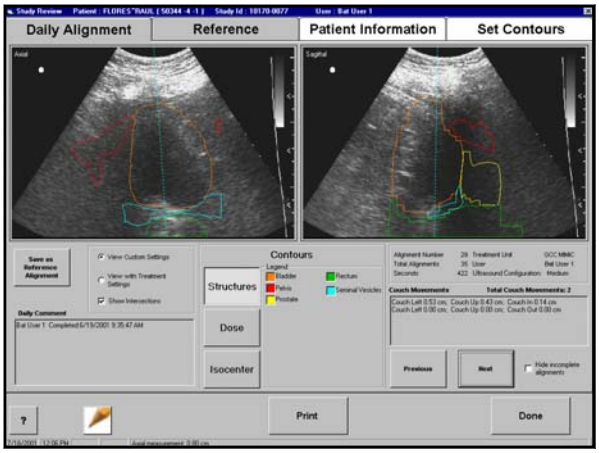


Example of BAT patients

- 62 year old treated for prostate cancer
- He presented to UH in 1998 with a PSA of 20.6. He had a needle biopsy performed that revealed an infiltrating moderately differential adenocarcinoma,
- It was T1C (tumor on needle biopsy of non-palpable mass)
- Gleason grade 3 (3+0 or 2+1?)
- He received hormone treatment and his PSA dropped to 6.8 in 5/99

BAT patient continued

- He was recently referred to the CTRC for evaluation for radiotherapy
- He received 7700 cGy to his prostate in 33 fractions
- The following slide is his image on the BAT and illustrates an image that is difficult to overlay with Corvus outlines



Problems for US Prostate Imaging

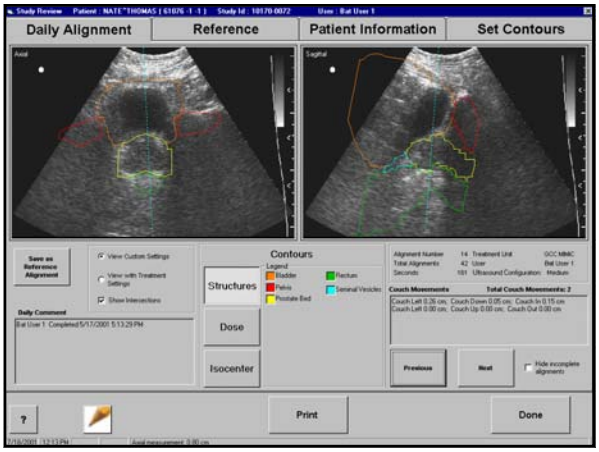
- Low bladder volume
- Small size of prostate
- Large body habitus (thick abdominal wall)
- Occasionally deep pelvic bowel (transverse colon)

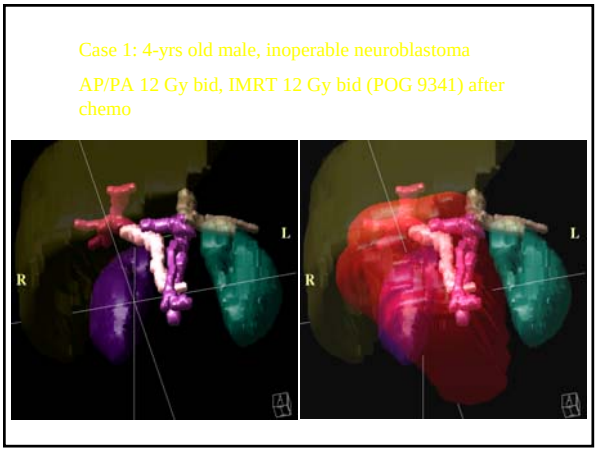
BAT patient continued

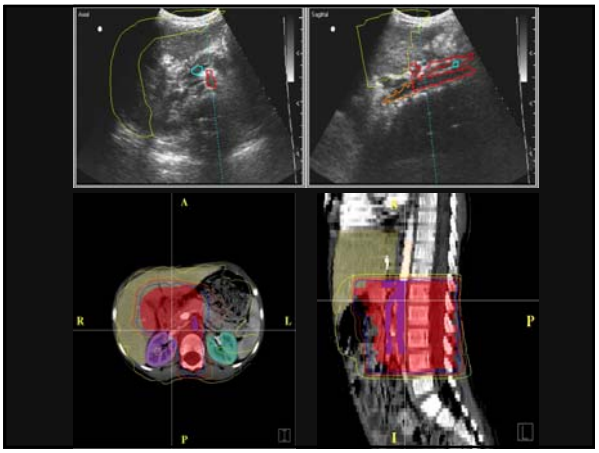
- 66 year old also referred to the CTRC for treatment of prostate cancer
- He is a VA patient who had a PSA of 4.2 in 1998
- In 9/2000 his PSA was 10.1
- His biopsy showed adenocarcinoma with a Gleason score of 6
- T3 (Tumor invades capsule or adjacent structure, but is not fixed)

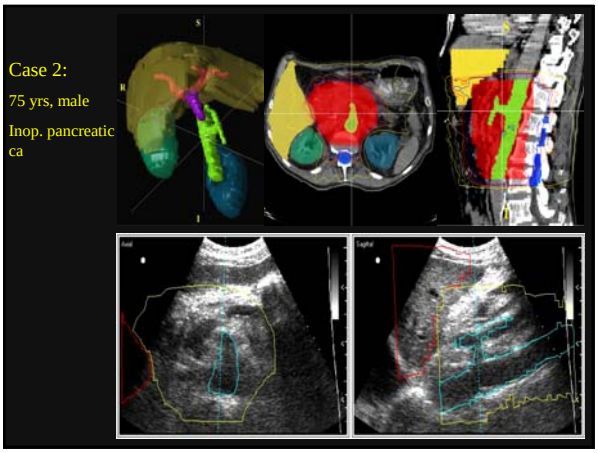
BAT patient continued

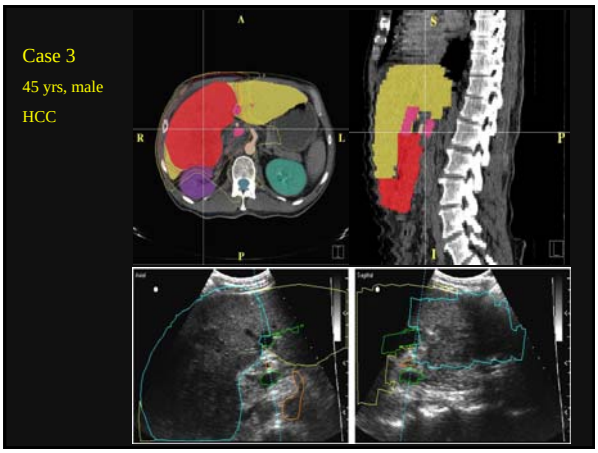
- He was treated with 7400 cGy to his prostate
- 30 fractions of 200 cGy
- A boost of 1400 cGy in 7 fractions
- The following slide is his image on the BAT and illustrates an image that was easy overlay with Corvus outlines





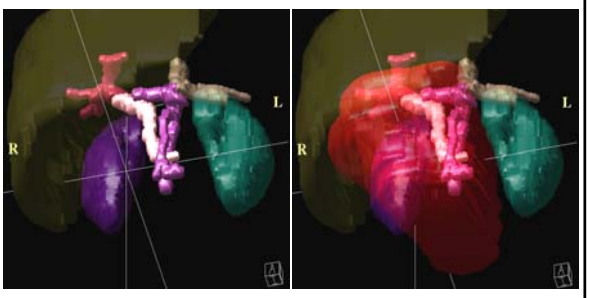


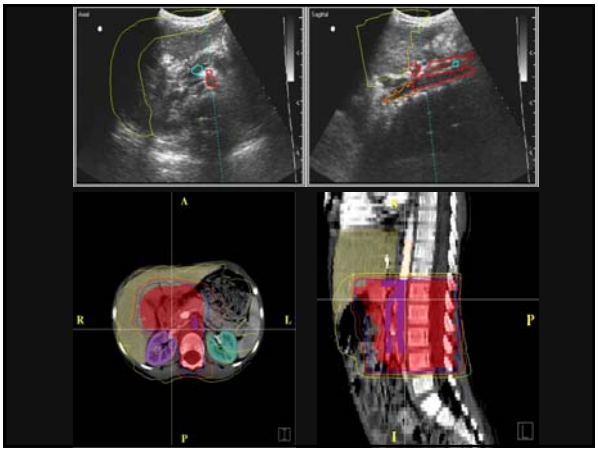


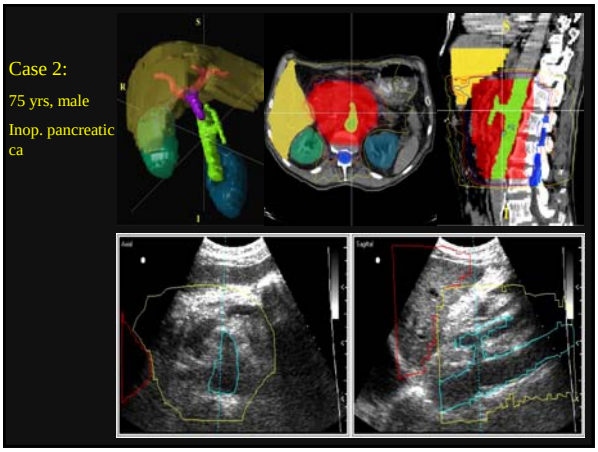


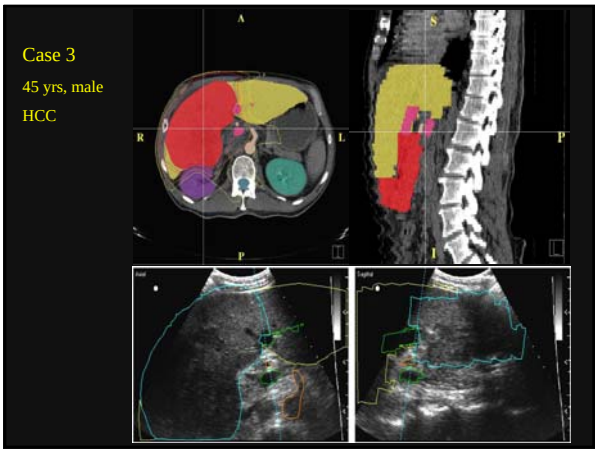
Case 1: 4-yrs old male, inoperable neuroblastoma

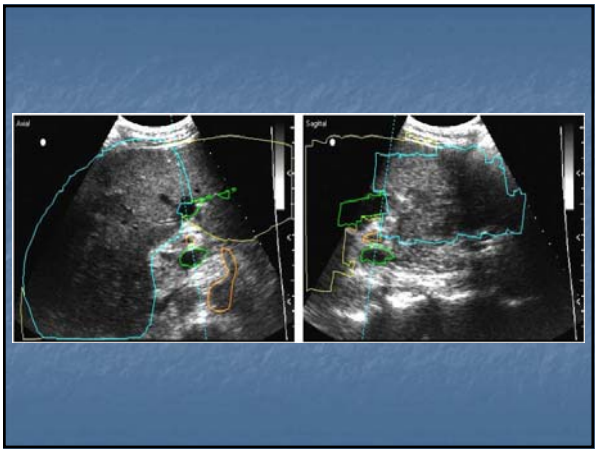
AP/PA 12 Gy bid, IMRT 12 Gy bid (POG 9341) after chemo

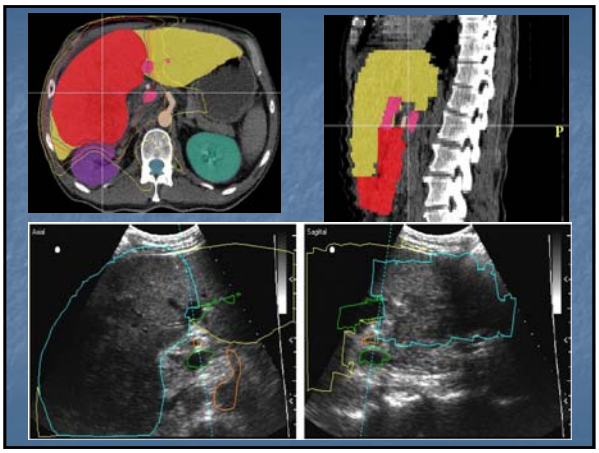


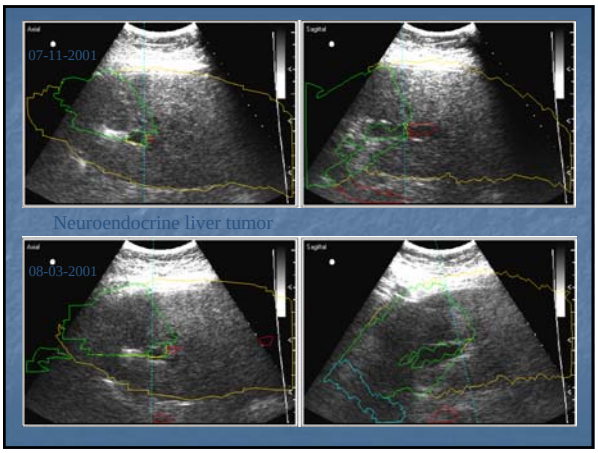








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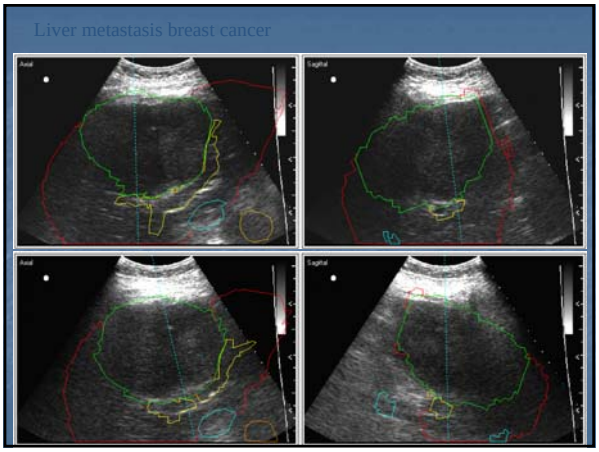
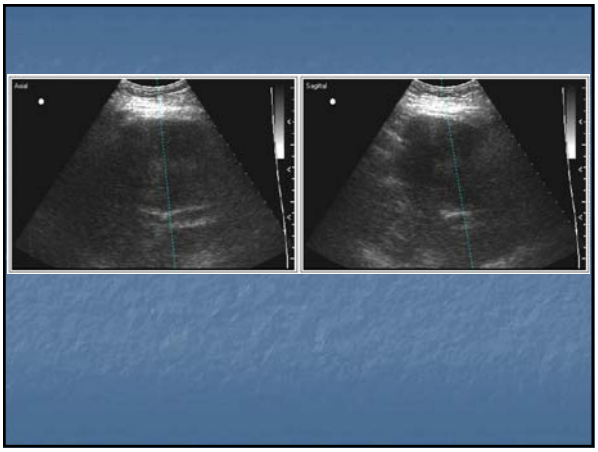
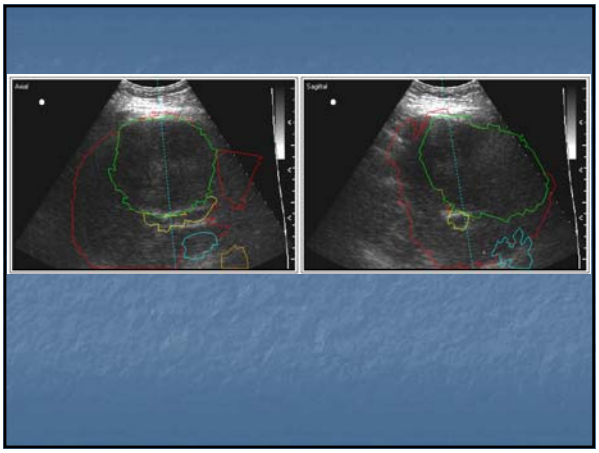
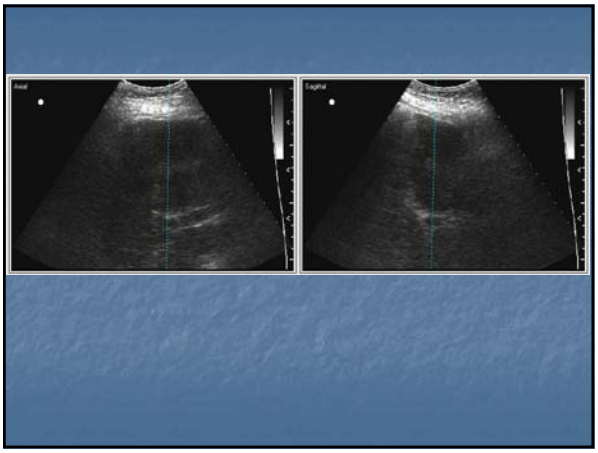
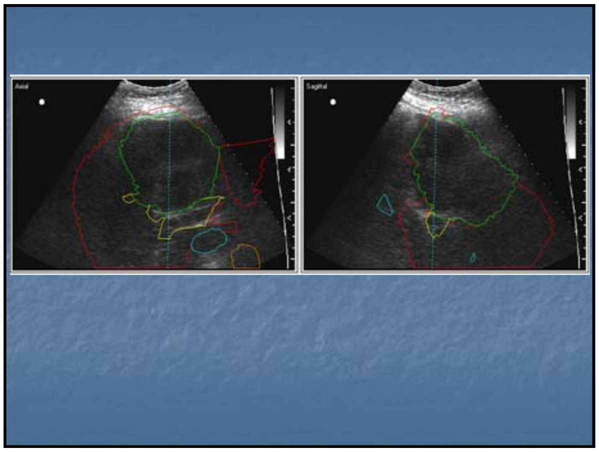
Neuroendocrine liver tumor
08-03-2001

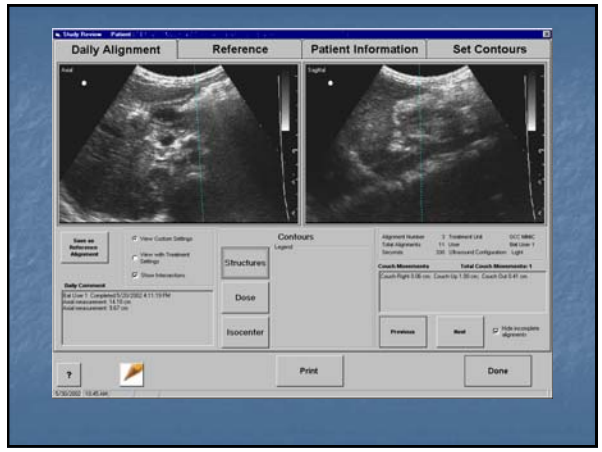

Liver metastasis breast cancer







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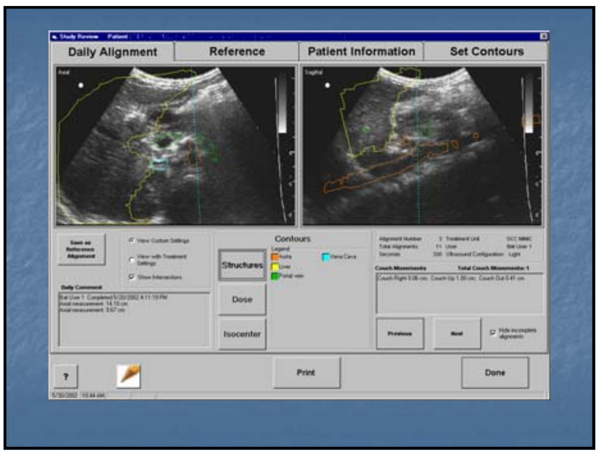
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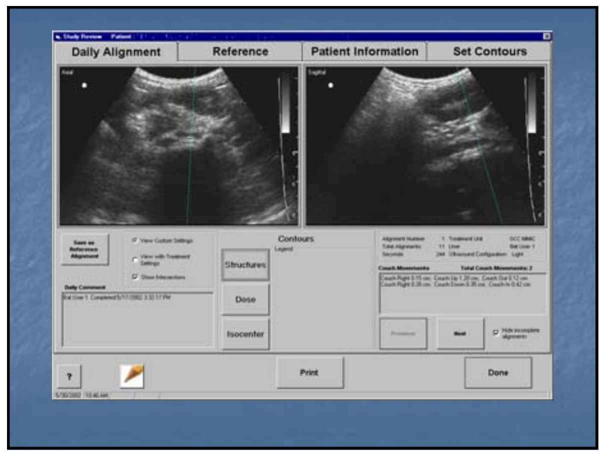
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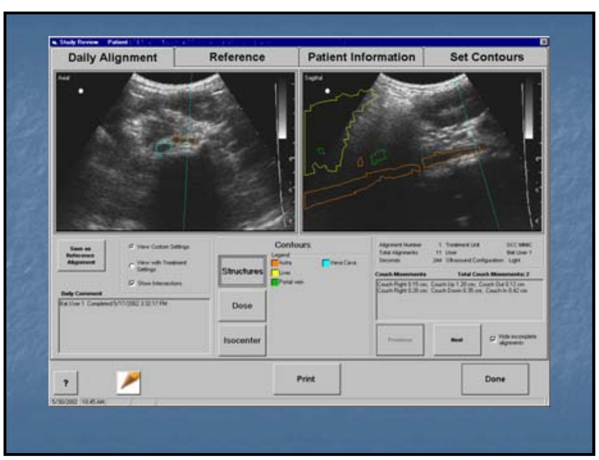
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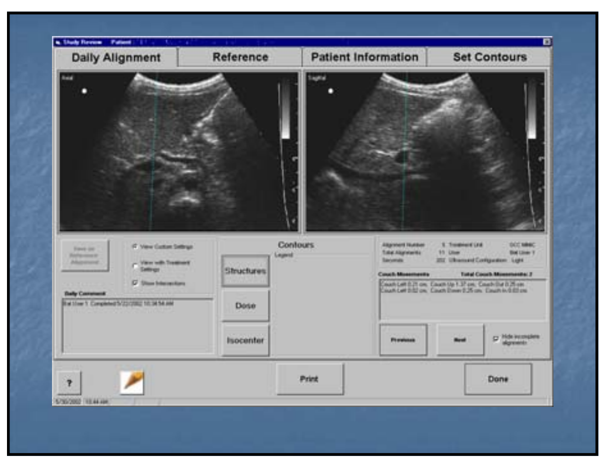
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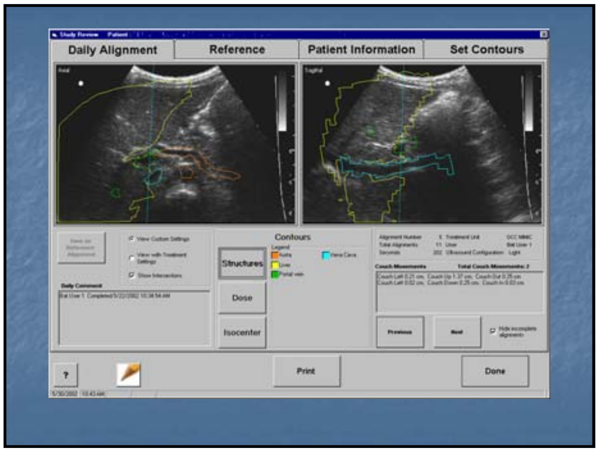
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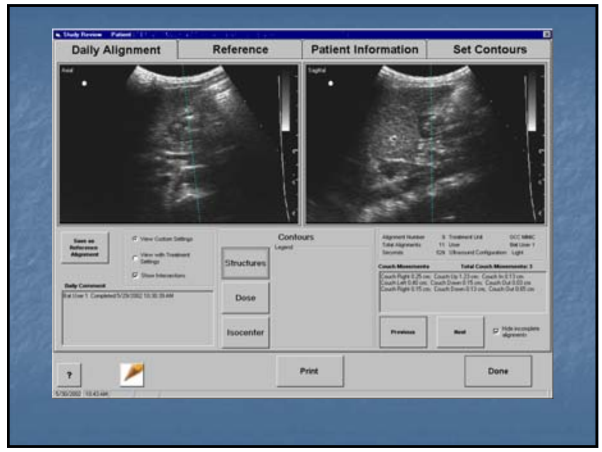
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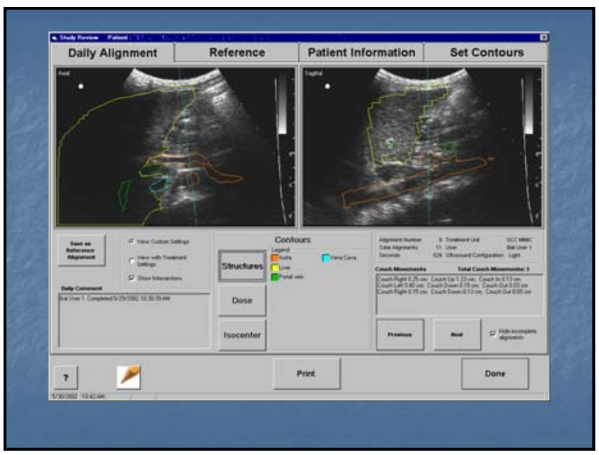
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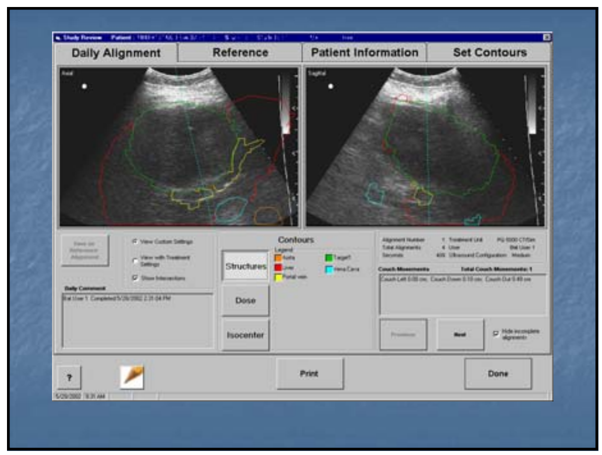
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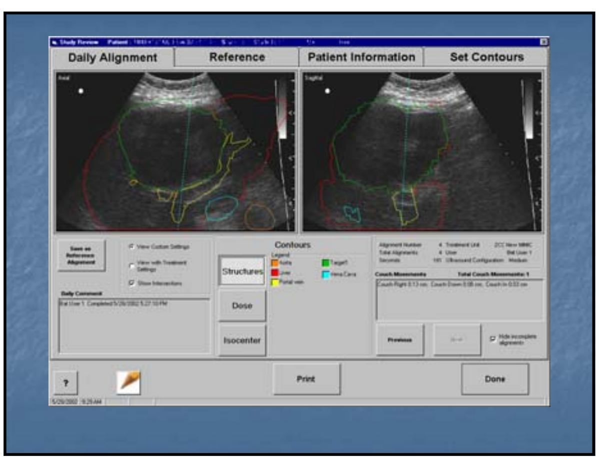
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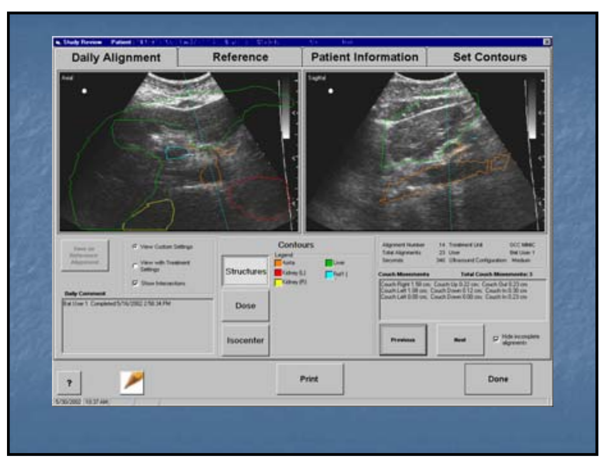
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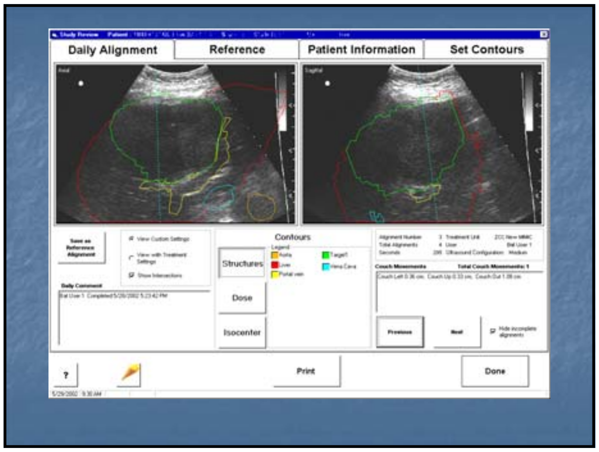
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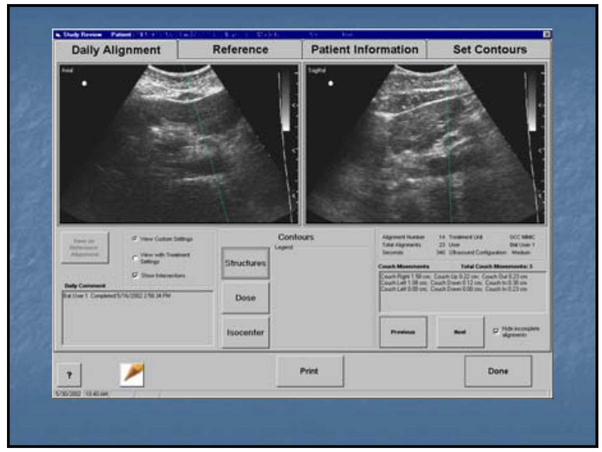
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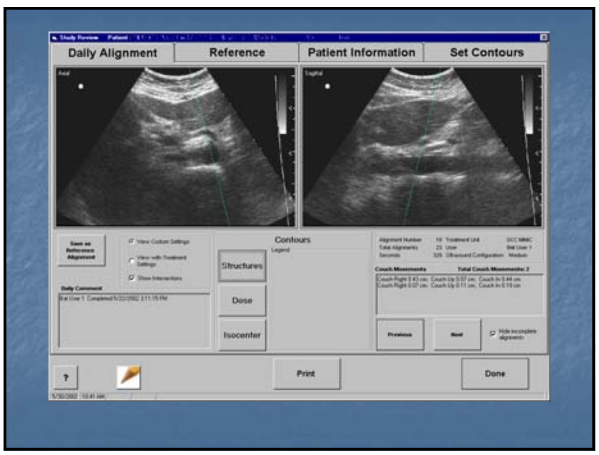
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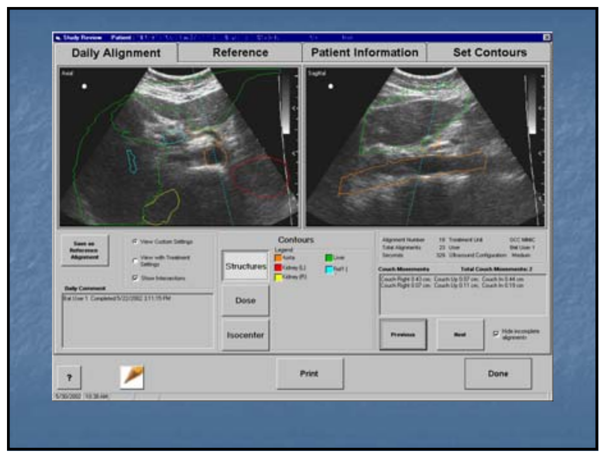
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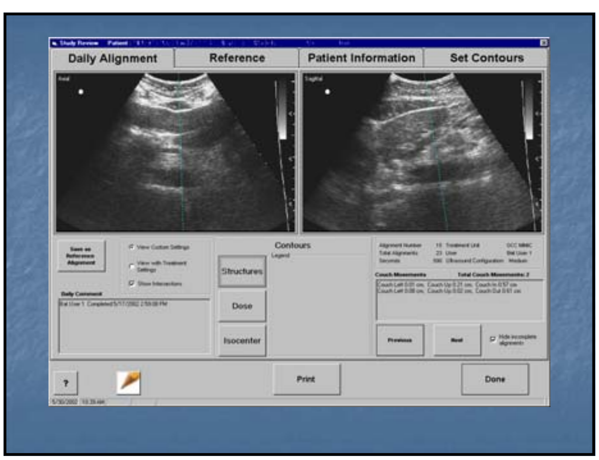
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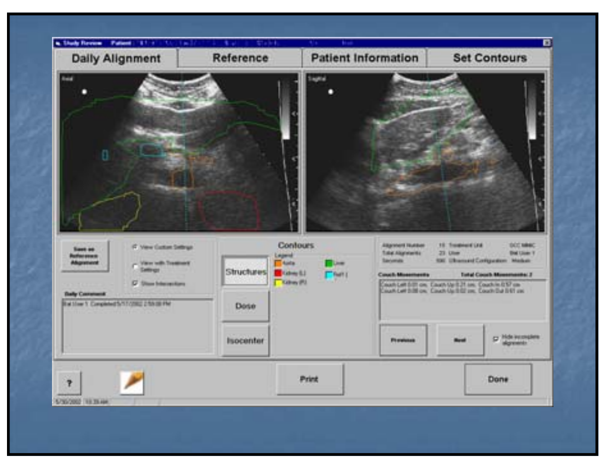
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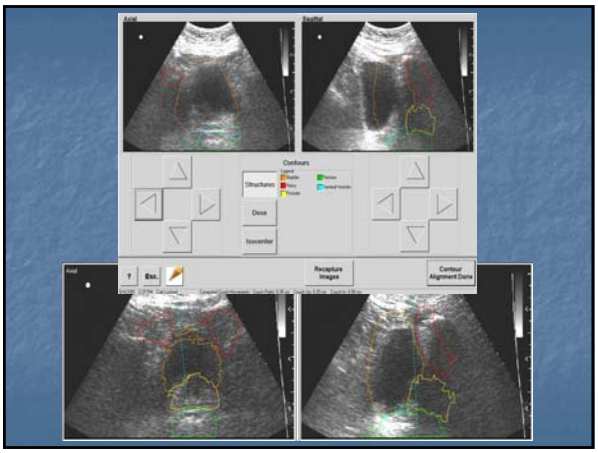
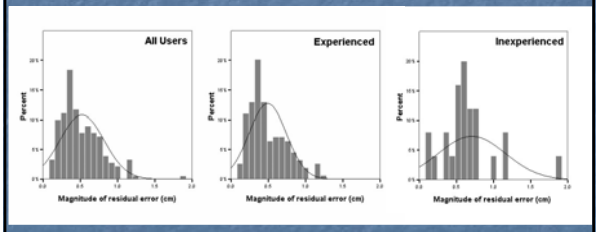
Positional variation of the prostate gland within the pelvis

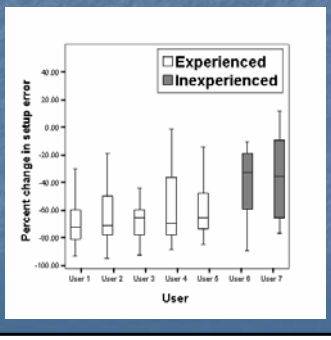
- Balter et al. IJROBP 1993 — 12 mm (95% CI)
- Roach et al. IJROBP 1994 — 7.5 to 22 mm (non-uniform)
- Lattanzi et al. Urology 2000 — 15 to 20 mm
  - initial skin mark based setup errors derived from BAT shifts



Objective assessment
magnitude of residual setup error



Objective assessment
percent change in setup error



Objective assessment
percent change in setup error