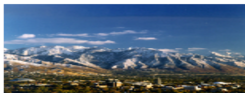

THE UNIVERSITY OF UTAH

HUNTSMAN CANCER INSTITUTE UNIVERSITY OF UTAH

Ultrasound Based IGRT

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Huntsman Cancer Institute

Acknowledgements

- Varian
- Resonant
- Nomos
- Martin Fuss

TG 154

Quality Assurance of Ultrasound Guided RadioTherapy

- **Charge -** To produce a guidance document for clinical medical physicists describing recommended quality assurance (QA) procedures for ultrasound-guided external beam radiotherapy localization.

US Guidance Experience

- Started USG 2000 – Fall 2005 (UTHSCSA)
- 2005 – Present U of U
- 3 US Guidance Units at UTHSC (Nomos BAT)
- 2 US Units at U of U (Nomos BAT)
- 10,000+ patient alignments
- Evolved system to use in liver and pancreas
- Mistakes? We've made them all!

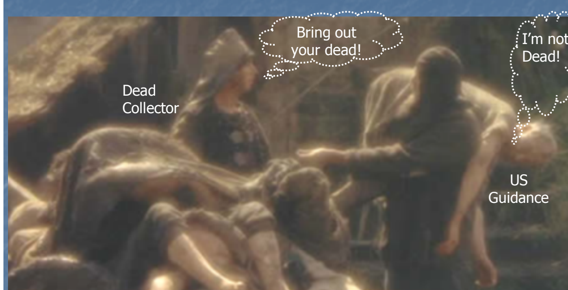
Ultrasound Based Image Guided Radiation Therapy
US-IGRT

Ultrasound Based Image Guided Radiation Therapy
US-IGRT

IGRT Modalities

- kV Cone Beam CT
- MV Cone Beam CT
- RF Transponder tracking-"Body GPS"
- CT on Rails
- kV stereoscopic planar imaging
- US what?

Ultrasound Based Image Guided Radiation Therapy
US-IGRT



Monty Python's Holy Grail

US Guidance - Relevance

- 600-700+ systems sold
- If only half of these are still active…
- And each site only aligns 3-4 patients daily
- There are still over 1,000 patient alignments performed daily.
- Or, over 250,000 annually.

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
- Alternate sites of application
- Recent observations

Why do we need in-room imaging?

"Back in the day"

- In the mid to late 90's when IMRT was introduced…
- We saw that we could create extremely conformal dose distributions (using a revolutionary idea => arc-based IMRT ☺)
- A first big site of application was for prostate…
- But we quickly realized that prostates move.

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

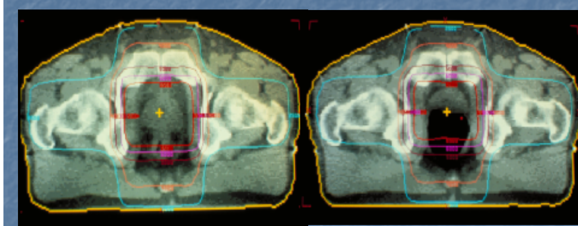
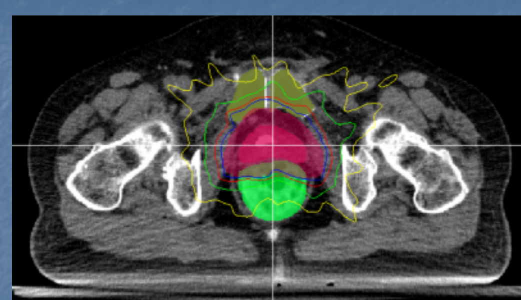
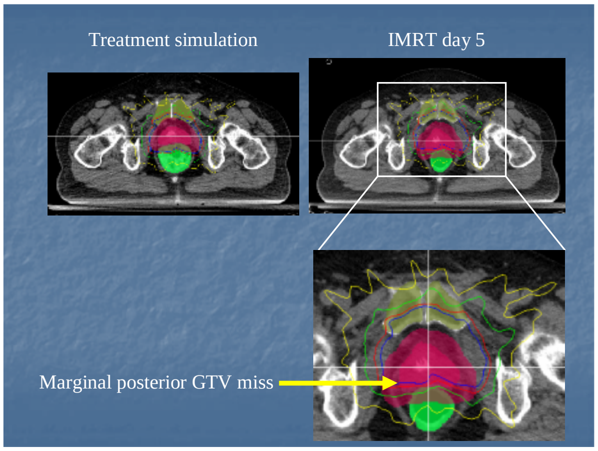


Image courtesy of Dr. David Hussey

Rationale for Image Guidance

- Problem: tight PTV margins and conformal dose distributions can lead to target miss.
- A miss is 100% error.





Causes of prostate positional variability

- Bladder filling
- Rectum filling
- Bladder and rectal contrast at RT planning

Potential dosimetric consequences of missing the target

- If target moves posteriorly, then the posterior aspect of prostate can experience dose reduction
  - Malignant cell density is often very high in the posterior and apical aspect of the prostate
- Increased rectal wall dose
- Increased bladder floor dose

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

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

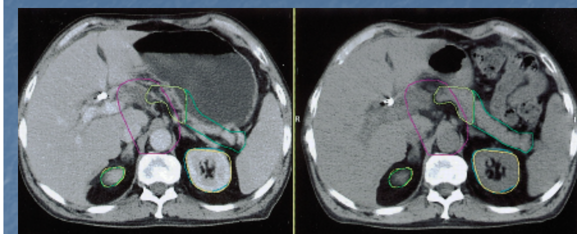


Figure 2. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue) and the target contour (violet) on the transverse non-contrast CT scan (right) project on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract) CT scan (left). The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

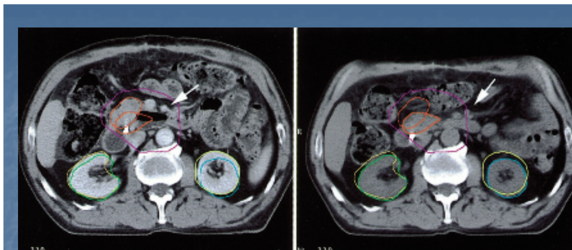


Figure 3. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue), pancreatic head contours (orange), and the target contour (violet) on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract CT scan (left) project on the transverse 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.

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

Characteristics of a successful in-room imaging approach for prostate or other abdominal targets

- Must be capable of directly ascertaining the room-coordinate location of prostate, or other targeted structure.
- 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 e.g. respiratory induced motion.

What are our options for acquiring targeting information for the prostate or other abdominal targets?

- 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)
  - Inexpensive
  - 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?
  - Expense

What are our options for acquiring targeting information for the prostate or other abdominal targets?

- 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
  - Large patient and hip prosthesis exclusion
  - Beacon migration/deformation (i.e. high GR)?
  - No follow up MRI after implantation
  - Expense?
- Ultrasound guided targeting
  - Non invasive
  - 'Real time' assessment of target and critical structure location
  - Intrafractional motion visualization, depending on method
  - Inexpensive
  - Inter-user variability in positional assessment/Accuracy
  - Unfamiliar imaging modality

Before you decide I've played favorites…

- We currently have and use all of these tools at the U of U.

Ultrasound Guidance Rationale

- Must be capable of directly ascertaining the 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)

- The ability to at least visualize the intra fractional component of motion might be valuable, as well e.g. respiratory induced motion.

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In Room US Image Guidance Process

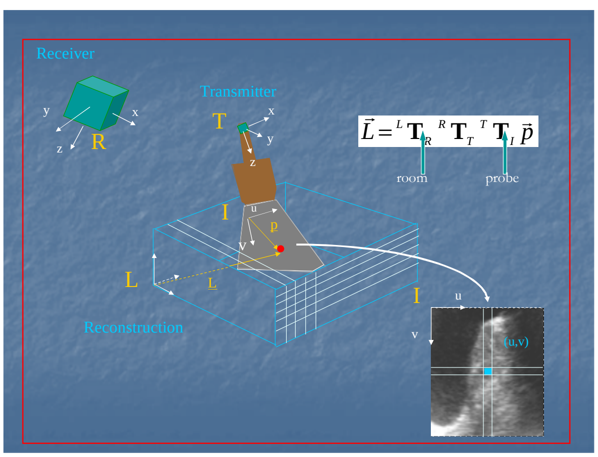
- We need to verify that the target and critical structures are in the same position(s) as they were for simulation.
- In-room verification of this allows us to verify correct position immediately prior to treatment.

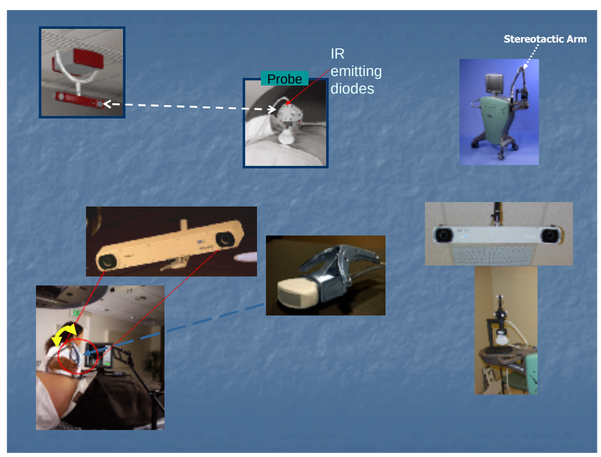
In Room US Image Guidance Process

- 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.

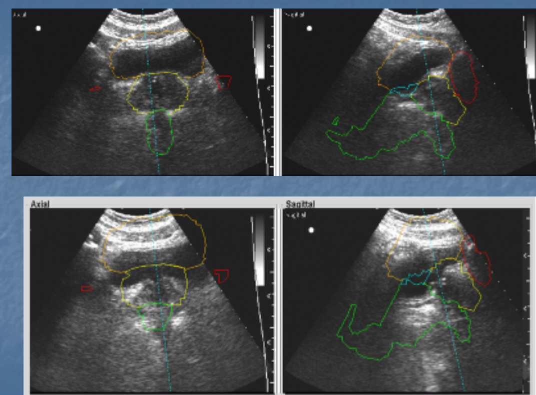
In Room US Image Guidance Process

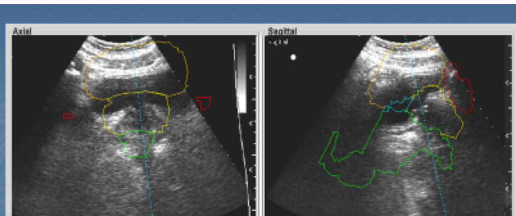
- If the position and orientation of the <u>US probe</u> is known, in room coordinates, then the pixels within the US image can be assigned room coordinates, thus giving the structures visualized in the US image known locations in room coordinates.



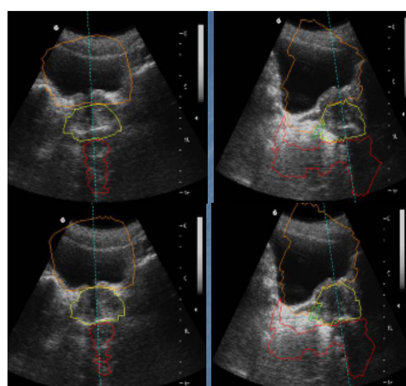


- By mapping the in-room-acquired US images to the same spatial reference frame as the simulation data set…
- We enable the direct comparison of the two data sets.
- This can be done, for instance, by overlaying the CT-Sim-derived contours of the target and critical structures onto the US image.





- The simulation derived contours are overlaid in room coordinates (i.e. relative to isocenter) 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.

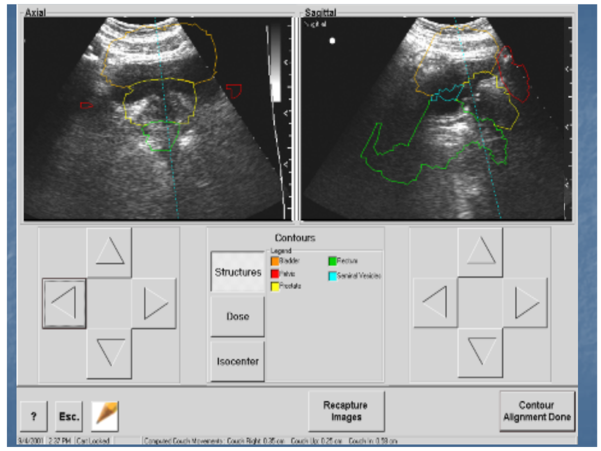


PRE ALIGNMENT

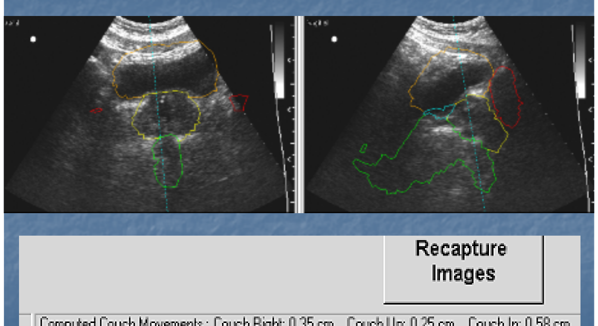
POST ALIGNMENT

COUCH MOVEMENTS: Left 0.160cm; Down 0.761cm; Out: 0.410cm

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

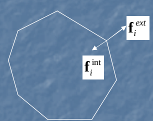


Ultrasound-based image guided targeting



- 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



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

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

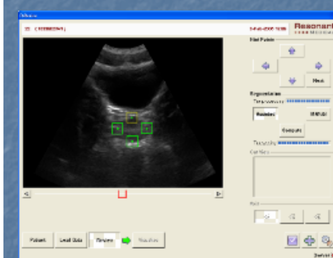
$$E(x,y) = \left\|\nabla\left(G_\sigma I(x,y)\right)\right\|$$

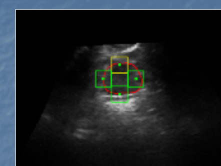
$$\mathbf{f}_i^{\text{int}} = \left(\mathbf{c}_i \cdot \hat{\mathbf{r}}_\mathbf{i} - \left\langle \mathbf{c}_i \cdot \hat{\mathbf{r}}_\mathbf{i} \right\rangle\right)\hat{\mathbf{r}}_\mathbf{i}$$

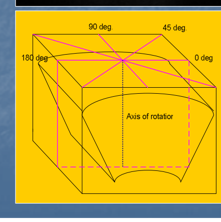
$$\mathbf{f}_i^{d} = w_i^{d}\mathbf{v}_i$$

- 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

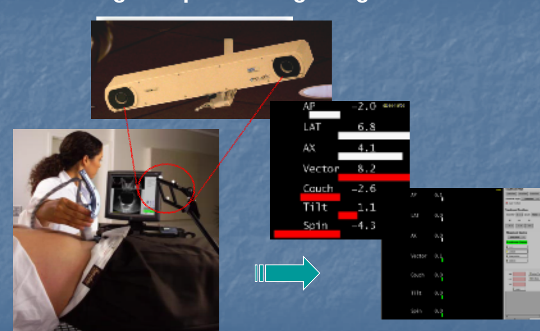






- However we determine the magnitude of displacements of the target, either by helping the system or by having it determine the shifts for us…
- We need to then implement the shifts.
- We now know that the target and critical structures are out of place relative to simulation…
- And we now need to move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

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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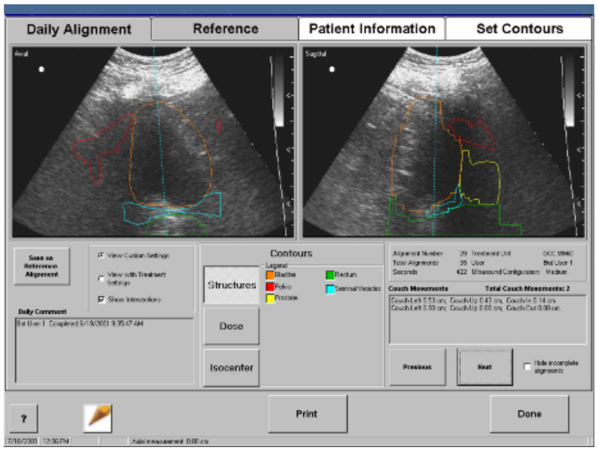
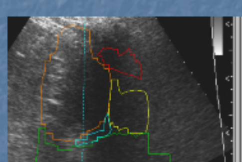
- Requires that the user acquire meaningful planar images.

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?

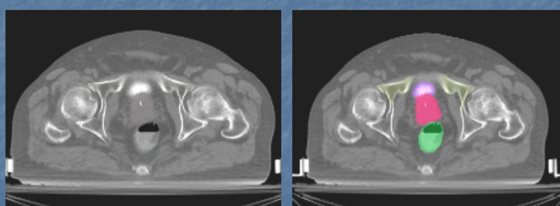


- It is very important that the contour of the prostate be drawn "anatomically correct", versus the physician drawing the region around the prostate that they wish to treat.
- If the "anatomical" prostate is not drawn, then the contour will not "fit" the image of the prostate seen on the screen.

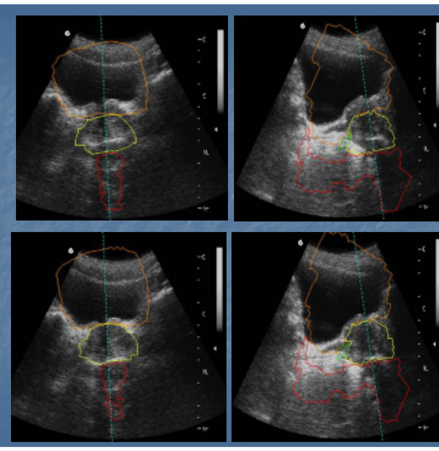


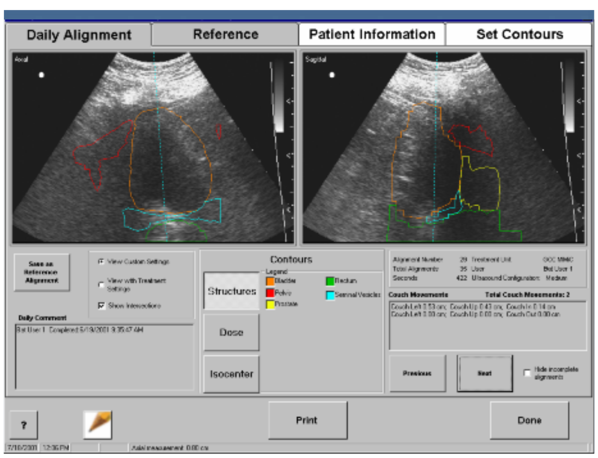
Target and organ-at-risk delineation

Is critical to the process.



Win or lose based on this step.

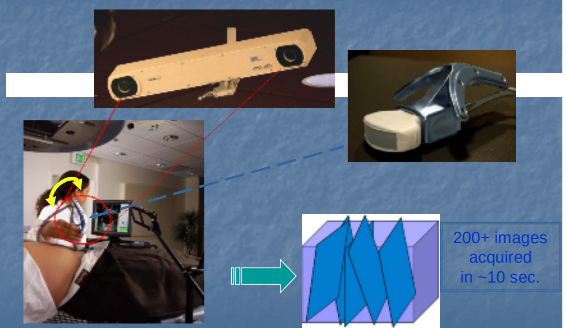




Vendor specific variations on the process

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

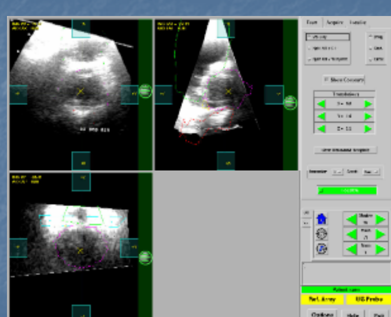
SonArray-
3D Ultrasound Image Acquisition



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 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.

Overview

- Rationale for in room Image Guidance
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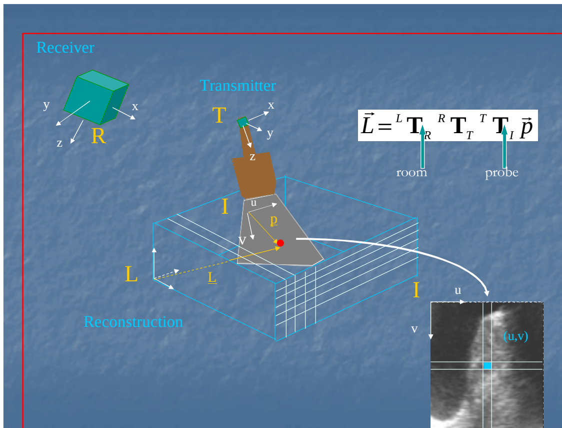
- Dosimetric implications
- Applications other than prostate

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 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.



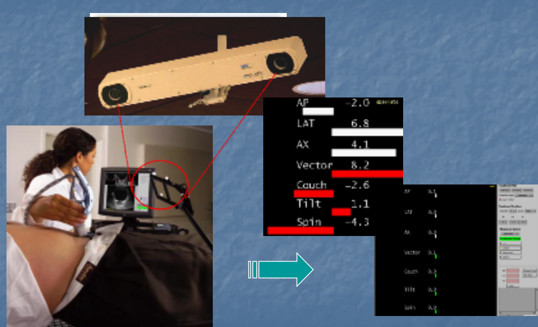
Key Components of the Process

- **US Image Quality**
- The inherent quality of the US image determines what structures are visible.
- The quality of the images will strongly 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**
- 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) 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.
- 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.

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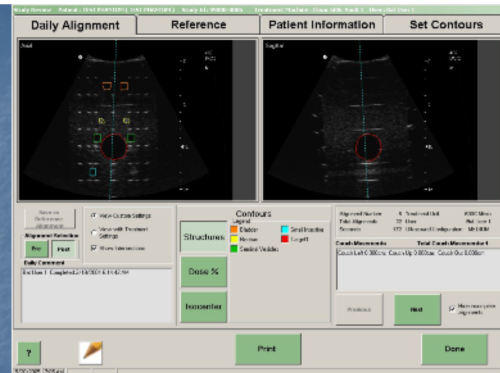
Implementation and QA Considerations

- 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.

Can also measure distance between known objects

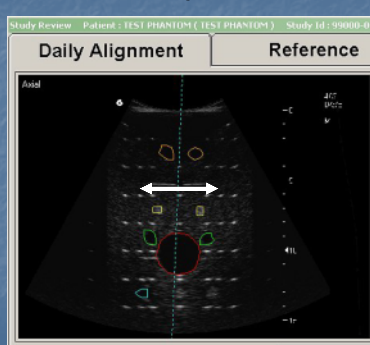
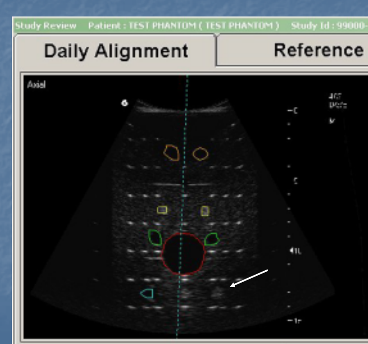


Image quality baseline



QA : 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, Ginzton Technology Center, Palo Alto, California

Peter Littrupp
Department of Radiology, Barbara Ann Karmanos Cancer Institute, Wayne State University, Detroit, Michigan 48201

Mubashra Khan, Yue Wang, and Jeffrey D. Forman
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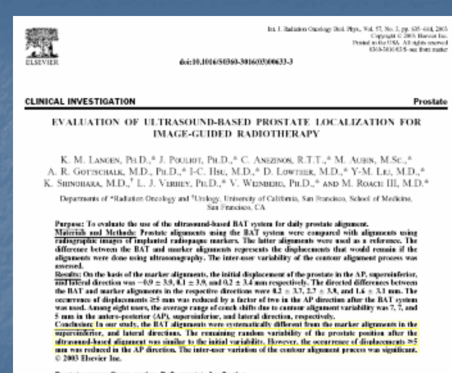
(Received 19 May 2003; revised 7 August 2003; accepted for publication 19 August 2003; published 14 October 2003)

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.

[DOI: 10.1118/1.1617354]



ELSEVIER

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0360-3016/03/$–see front matter

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CLINICAL INVESTIGATION **Prostate**

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

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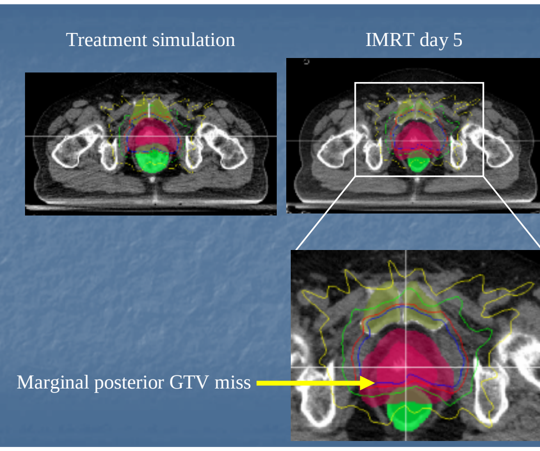
Purpose: To evaluate the use of the ultrasound-based BAT system for daily prostate alignment.
Materials and Methods: Prostate alignments using the BAT system were compared with alignments using radiographic images of implanted radiopaque markers. The latter alignments were used as a reference. The difference 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, 0.1 ± 3.9, 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 ± 3.9, 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.
Conclusion: 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.

- Most reports agree 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.



Not all recent reports are critical…

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

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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

www.tcrt.org

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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:

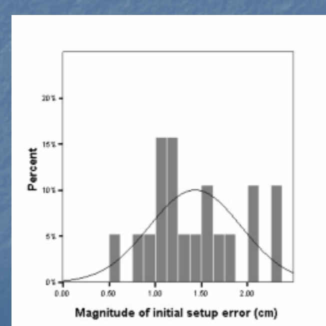
- 20 patients
- Radiation oncologist (1)
- Physicist (1)
- RT/T (4)
- Radiologist (1) (user gold standard)

Study design

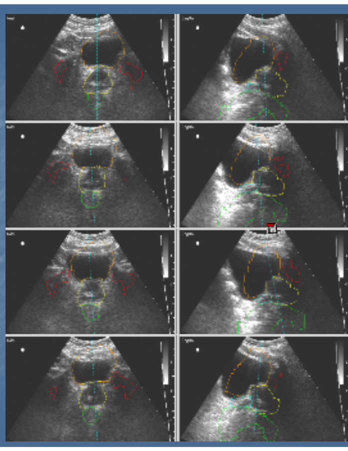
- BAT setup for use in the CT suite
- BAT calibrated to imaging plane of the CT
- Lasers aligned to skin marks
- BAT used to measure prostate misalignment
- Each user's indicated shifts recorded
- Patient CT immediately after BAT

Objective assessment

initial prostate displacement



mean 14.3 mm



Magnitude of initial setup error: 13.5 mm

User A
Shifts: Left 13.5, up 8, in 0.6 mm
Magnitude of residual error: 3.8 mm
Percent improvement: 71.9%

User B
Shifts: Left 12.8, up 6, in 2.9 mm
Magnitude of residual error: 2.4 mm
Percent improvement: 82.2%

User C
Shifts: Left 13.3, up 6.5, out 1.8 mm
Magnitude of residual error: 4.0 mm
Percent improvement: 70.3%

User D
Shifts: Left 13.1, up 6.6, in 1.8 mm
Magnitude of residual error: 3.2 mm
Percent improvement: 77.3%

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
- US alignment can be performed with good interuser consistency, and led to improved treatment setup.
- Experienced use is correlated with a higher degree of setup improvement

How do we create capable, experienced users and QA their performance?

- Weekly review sessions
- Supervised by most experienced user (e.g. physician or physicist)
- Display daily alignment images on large screen and discuss using laser pointers
- Evaluate images for: useful information, image quality and alignment.
- Experienced user called to vault for next alignment of challenging patients.

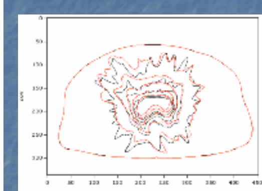
- Having shown that acceptable inter-user consistency can be achieved with a good training process, does improved spatial alignment translate into significant dosimetric improvement?

Study Design

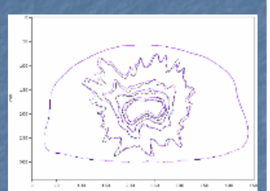
- 20 patients under BAT USG treatment
- Recorded daily x, y, z treatment shifts
- Recalculated the isodose distribution for each daily fraction to determine what would have happened without BAT alignment
- Summed each recalculated fraction to create a composite isodose distribution for each patient, 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

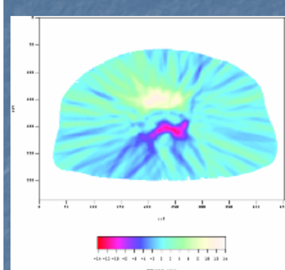


No US Alignment

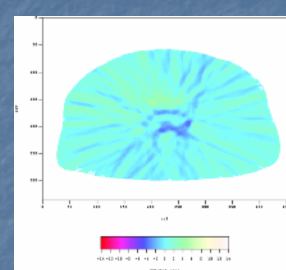


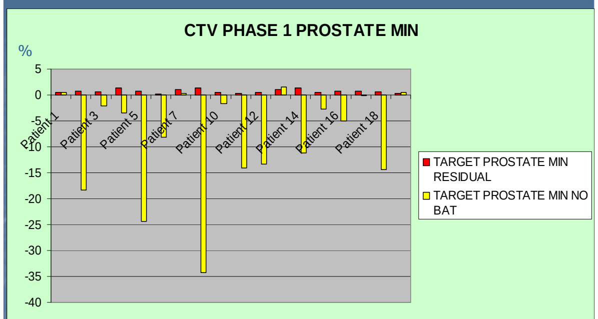
With BAT US Alignment

No BAT



With BAT





CTV minimum dose, percent difference from prescribed.

We Concluded…

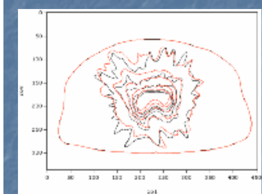
- In addition to improved <u>spatial alignment</u> of prostate target
- USG also leads to significant improvement in <u>delivered dose</u>

We Concluded…

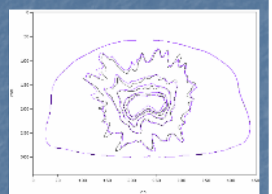
- And so we saw in our clinic, at least, that…
- If we trained our staff to use the USG system, we could achieve consistent and significant improvements in setup quality
- With mean “residual” errors (when compared to CT) of ~3mm in any given direction.

We Concluded…

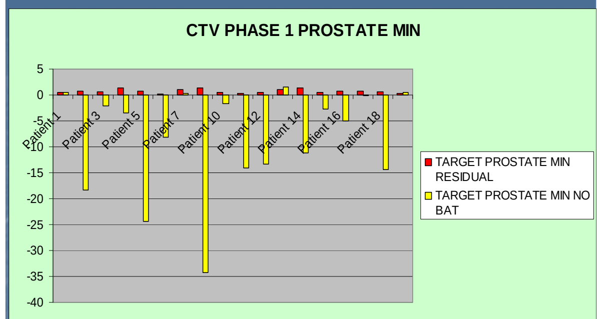
- We also saw that when we recomputed the composite dose distributions for our patients and included the residual error in target position characteristic of what our staff typically “left behind”
- The dose distributions were much better



No US Alignment



With BAT US Alignment



CTV minimum dose, percent difference from prescribed.

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
- Applications other than prostate
- Recent observations

Other sites for application of USG

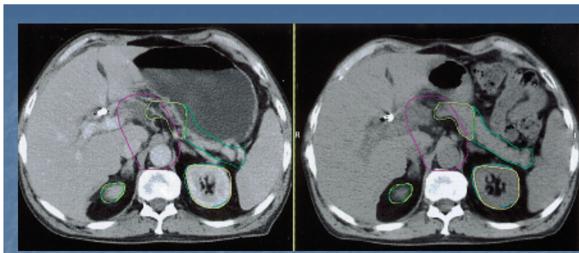
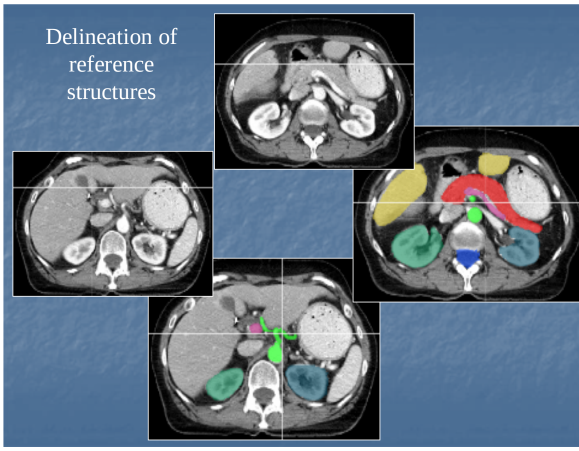
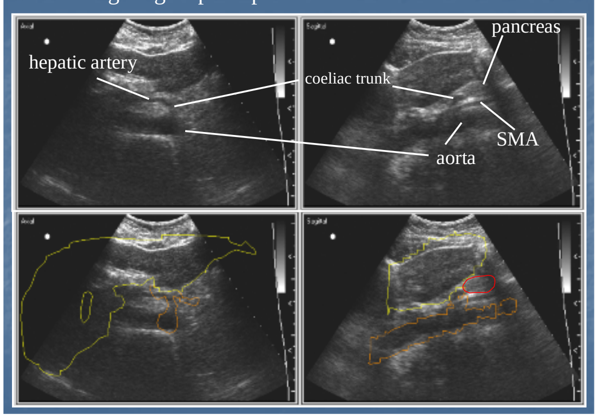


Figure 2. CT scan to CT scan registration. Kidney contours (yellow, light green, light blue) and the target contour (violet) on the transverse non-contrast CT scan (right) project on the transverse negative contrast material (high fluid content of proximal gastrointestinal tract) CT scan (left). The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

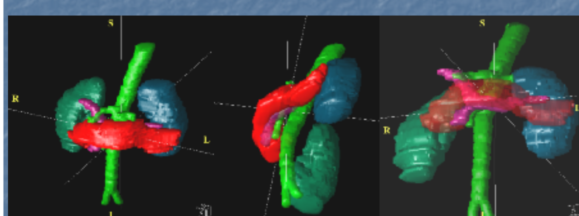
Delineation of reference structures



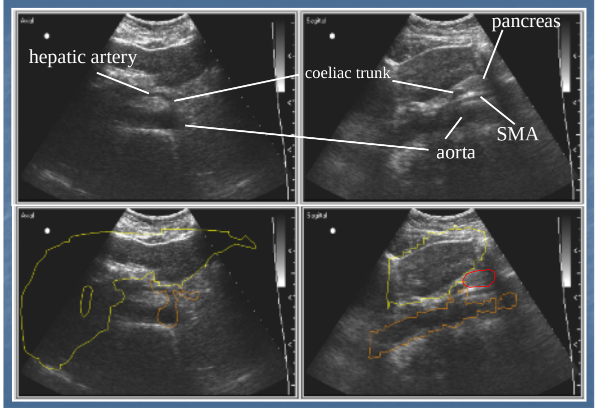
US targeting: superimposition of CT derived structures

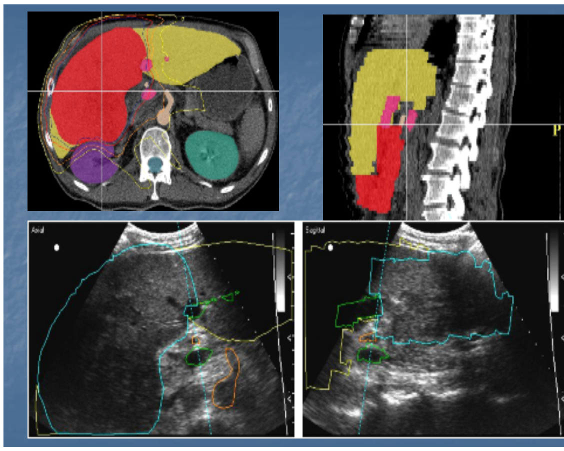


Pancreas 3D reconstruction



US targeting: superimposition of CT derived structures



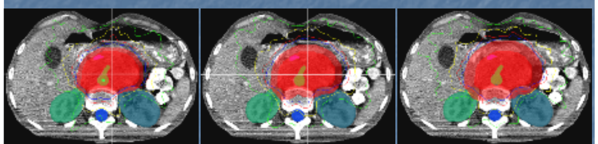


Correlation of BAT and CT positional control

- 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?

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**

Reduction of over 300 cc healthy tissue treated

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

Martin Fuss, M.D.,[†] Bill J. Salter, Ph.D.,[†°]
Sean X. Cavanaugh, M.D.,[†*] Cristina Fuss, M.D.,[§] Amir Sadeghi, Ph.D.,[°]
Clifton D. Fuller,[*] Ardow Ameduri, M.D.,[°] James M. Hevezi, Ph.D.,[°]
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.,[†°]
Terence S. Herman, M.D.,[†] Charles R. Thomas Jr., M.D.,[†]
Gastroenterology. 2004 Nov; 127(5 Suppl 1):S206-17. Review.

We Concluded…

- 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.

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
- Other sites of application
- Recent observations

Probe Pressure

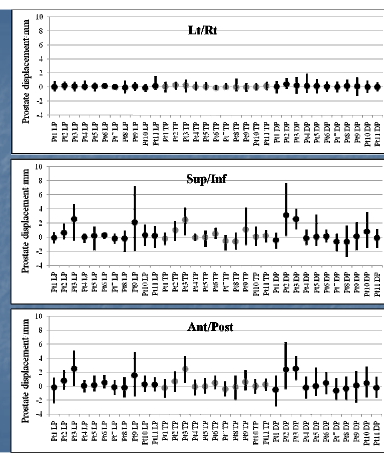
- Concern over the effects of probe pressure have been expressed since the advent of US-IGRT.
- Various reports have been published attempting to characterize the phenomenon.
- All used "snap shot" approaches where pressure was applied/simulated and some measurement of prostate position performed.
- Reported results range from 2-16 mm A/P displacement.

Probe Pressure

- We conducted a study on 20+ patients treated in our clinic (over 500 fractions) who were already implanted with Calypso transponders.
- We applied probe scanning pressures of "light", "typical" and "deep" while Calypso tracking was occurring…
- And we measured prostate displacement during and in the minutes following application of pressure.

Probe Pressure - Observations

- For the typical pressure scenario we observed mean posterior displacements of ~1 mm, with single instance maximum values of 2.3 mm and 3.0 mm observed for the Typical and Deep scenarios, respectively.
- We concluded that for even the clinically unrealistic "deep" pressure scenario, displacements were relatively small.

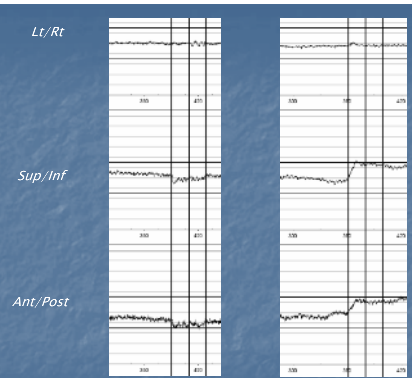


Probe Pressure - Observations

- Besides posterior displacement due to *direct* mechanical pressure transmitted from the US probe, a s**timulus/response** or **Reflex Response** phenomenon, which resulted from merely lightly touching a sensitive area such as the lower abdomen, was also seen to contribute significantly to prostate displacement.

Probe Pressure - Observations

- **This factor typically caused the prostate to move anteriorly and superiorly, i.e. in the opposite directions to direct pressure results, thus serving to somewhat cancel out the mechanical displacement component.**
- This phenomenon was most easily observed and quantified for the **Light Pressure scenario** when virtually no pressure was applied.



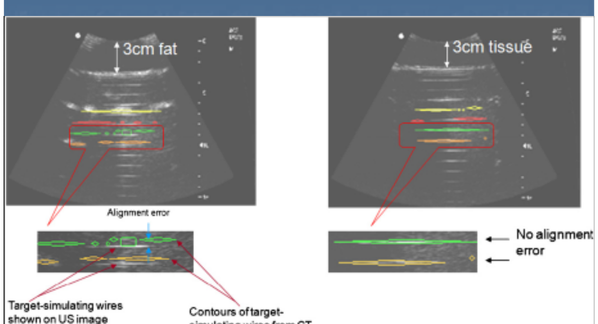
a) Direct mechanical factor   b) Stimulus-response factor

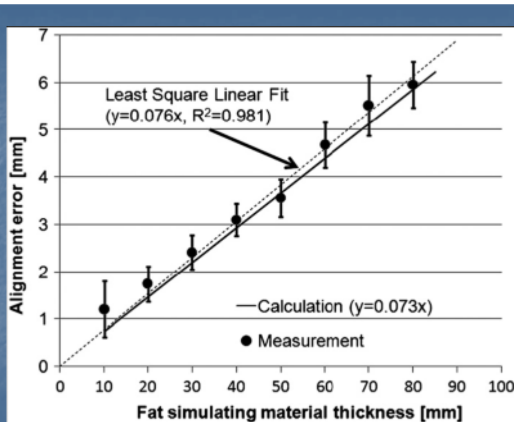
US Speed Artifact

- The speed of sound in fat is ~1435 m/s, while the speed of sound in tissue is ~1540 m/s.
- US guided systems are typically calibrated using tissue equivalent phantoms, and this seems reasonable since we mostly image through tissue.
- The problem arises when we image through non-trivial thicknesses of fat.

US Speed Artifact

- The slower speed of sound through fat aliases downstream structures deeper than they really are.
- We conducted a study to demonstrate this phenomenon in phantom and to quantify the magnitude of aliasing.





Concluded

- The US Speed Artifact manifests itself as aliasing of structures to locations deeper than they actually are for commercial US guided systems.
- The aliasing resulted in target alignment errors of ~0.7mm/cm-fat-imaged-through.
- The aliasing can cause the high dose region to be delivered slightly posterior to the intended location.
- Users should avoid imaging through thick layers of fat whenever possible.
- The good news is, we already avoid imaging through fat because it lowers the quality of our images.
- Working to develop CT-based correction strategy for obese patients

IOP Publishing — Physics in Medicine and Biology

Phys. Med. Biol. 53 (2008) N437–N445 — doi:10.1088/0031-9155/53/23/N03

NOTE

Evaluation of alignment error due to a speed artifact in stereotactic ultrasound image guidance

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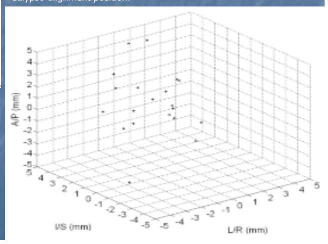
US-IGRT Accuracy

- At AAPM this year we presented preliminary results of a study we conducted wherein we compared US guided results to Calypso results.
- We performed US guidance on Calypso patients prior to aligning via Calypso and compared the results.
- Calypso guidance shifts were always used to align the patient for treatment.

	Mean (mm)			Standard Deviation (mm)		
	L/R (Left+)	I/S (Sup+)	A/P (Ant+)	L/R	I/S	A/P
Pt1	0.6	1.1	-0.7	2.1	3.5	3.6
Pt2	-0.3	2.9	-0.8	1.9	2.5	1.8
Pt3	-2.4	-0.9	7.9	2.9	3.0	3.9
Pt4	-3.6	1.2	1.1	1.9	2.3	3.0
Pt5	-1.6	-2.0	2.1	1.7	2.6	4.1
Pt6	-2.5	-1.5	3.0	1.5	2.5	2.7
Pt7	1.1	1.2	2.3	2.3	2.9	3.2
Pt8	1.0	-0.6	-2.3	2.1	5.0	2.8
Pt9	-1.2	2.2	5.8	1.6	3.6	3.7
Pt10	-0.1	2.9	1.2	1.3	2.1	2.4
Pt11	-2.1	2.3	3.3	2.0	2.4	4.2
Pt12	-2.3	1.9	2.4	2.6	2.6	3.1
Pt13	-4.9	-2.7	-2.9	1.9	1.8	3.9
Pt14	-0.5	3.5	-2.6	2.0	3.0	4.6
Pt15	-2.2	-2.9	1.9	1.7	2.1	3.4
Pt16	1.4	2.5	0.5	3.0	2.4	3.4
Pt17	-0.9	-1.6	4.1	3.7	2.8	4.6
Pt18	0.3	0.5	0.5	2.2	3.4	4.2
Pt19	-1.7	1.1	-0.6	2.7	2.6	4.0
Pt20	-0.7	-3.3	1.1	2.7	3.0	3.2

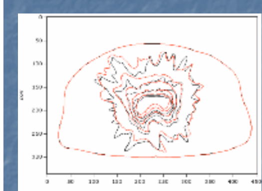
Table 1 presents summarized data for the 661 fractions evaluated here, showing that the BAT residual uncertainty has a mean ± standard deviation (SD) of -1.1 ± 2.7 mm (L/R), 0.3 ± 3.6 mm (I/S), 1.5 ± 4.5 mm (A/P). Our results are seen to agree well with a recent report from Heidelberg University1, which evaluated the BAT residual positioning uncertainty as compared with implanted fiducial fusion by cone beam (CB) CT as a gold standard. Their findings were 0.6±1.7 mm (L/R), 0.9±3.2 mm (I/S), -1.7±3.5 mm (A/P). We interpret the slightly larger standard deviation measured in our study as reasonable, given that the average experience of US alignment technicians in the Heidelberg group is likely greater than for our group, given the relatively recent adoption of US alignment technology in our clinic(~ 1.5 years). Both studies also show BAT standard deviation to be largest in the A/P direction. Figure 2 depicts a 3D scatter plot of mean BAT residual uncertainty for each of the 20 patients studied here, with the majority of patients seen to cluster within a bounding box of roughly ~3 mm or less as compared to Calypso alignment position.



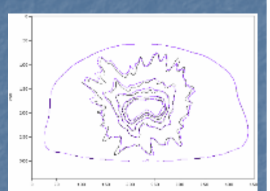
BAT vs Calypso

US-IGRT vs Calypso

- The residual errors observed were similar to those observed for our earlier study comparing against CT.
- The composite dose study we did using these residual errors showed good agreement with planned isodose distributions.

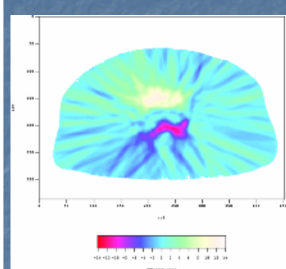


No US Alignment

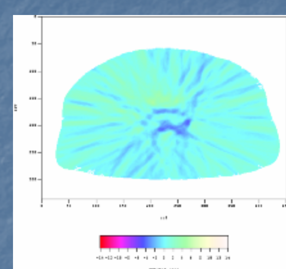


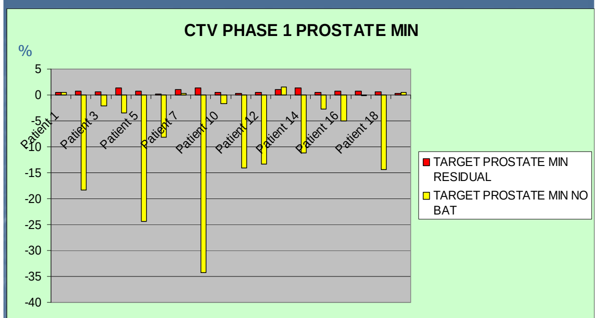
With BAT US Alignment

No BAT



With BAT





CTV minimum dose, percent difference from prescribed.

US-IGRT Accuracy

- So, while it appears clear that methods such as Calypso, which implant transponders directly into the target, are the gold standard in terms of accuracy…
- It also appears clear that US-IGRT is an effective Image Guidance approach for aligning soft tissue targets such that they receive delivered isodose distributions that are in good agreement with planned doses.

- In our clinic we typically use Calypso localization and tracking for patients who are candidates (i.e. not excluded due to obesity, hip prosthesis, blood thinners or by refusal to consent for the invasive procedure)
- And we use US-IGRT for the others.
- We also use US-IGRT at our local satellite facility where Calypso is not available.

In Conclusion

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
- Other sites of application
- Recent observations-Probe pressure, speed artifact and accuracy relative to Calypso.