Ultrasound Guided In-Room Imaging for Localization

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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!

In Texas
Redneck
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)

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

Image courtesy of Dr. David Hussey
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 is 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 3-6mm 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 (right) project on the transverse non-contrast CT scan (left). 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.

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**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 intrafractional component of motion might be valuable, as well.

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

- Implanted fiducial markers
  - Daily planar image (port film, EPID, stereo pair, fluoroscopy)
  - Objective and precise positional assessment of target
  - Intrafractional motion visualization while treating
  - Objective fiducial location
  - MSSD registration
  - Expand CT
- Implanted transponders
  - Objective fiducial registration
  - Objective and precise positional assessment of target
  - Intrafractional motion visualization while treating
  - Objective fiducial location
  - MSSD registration
  - Expand CT
- Ultrasound guided targeting
  - Non-invasive
  - Objective and precise positional assessment of target
  - Intrafractional motion visualization, depending on method
  - Objective fiducial location
  - MSSD registration
  - Expand CT

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**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
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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
- Publications critical of reproducibility.

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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.
- 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

- 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 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

Recapture Images

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

- 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
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?

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**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.

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

**SonArray - 3D Ultrasound Image Acquisition**

200+ Images acquired in ~10 sec.

**SonArray - Spatially Correlated 3D Image Registration**

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.

- 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.

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

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.
- 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.

**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.

**3D Target Repositioning / Alignment**

- **SonArray**

**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 Resitu 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 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

Perform daily, prior to start of patient treatments.

Image quality baseline

User interaction with system

Inter-user variability

Recently critically and controversially discussed
No one seems to argue that the process is good at eliminating large errors.

Not all recent reports are critical...
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)

Objective assessment

Initial prostate displacement

![Graph showing initial prostate displacement](image)

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 3 mm 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

What might cause such a systematic error?
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 😊


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?

Which seems to suggest...

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

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.

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.
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?

Let's have a look at a clinical IMRT treatment plan.

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

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GTV 231 cm³

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

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

Learning objectives

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

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.
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 intrafraction 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 sites 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

- 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 without BAT.
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So, does USG increase the probability of reaching early PSA nadir of 1.0 or less?

- Funny you should ask again 😊

Which seems to suggest...

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Liver metastasis breast cancer

Correlation of BAT and CT positional control
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Does it matter?

Let's have a look at a clinical IMRT treatment plan.
Inoperable pancreatic cancer (impact of PTV safety margin on normal tissue at risk for toxicity)

- 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

![Image](https://example.com/image1)

**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 translation and their length indicates interquartile ranges (q25-q75) in the two dimensions.

SMA

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

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![Image](https://example.com/image2)
Other abdominal target volumes

- Pancreas
  - Difficult to visualize in ultrasound
  - Individually close organ relation to major named vessels

- Neuroblastoma
  - Vertebrae bodies are part of the CTV/PTV
  - Often close relation to abdominal/retroperitoneal vessels
  - Most often close relation with one kidney/liver

Potential limitations

- Organ outlines may be helpful
  - Caudate lobe of the liver
  - Kidney outlines

- 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

US targeting: superimposition of CT derived structures

pancreas
SMA
coeliac trunk
aorta
hepatic artery
lienal vein
coeliac trunk
SMA
aorta
lienal vein
Kidney
Liver
Aorta
Coeliac trunk
SMA
Vena cava
Portal vein
Confluent

Target volume

07-11-2001
08-03-2001

Neuroendocrine liver tumor

Liver metastasis breast cancer

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±4.6 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)
Correlation of BAT and CT positional control

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Preliminary conclusion

- Daily stereotactic ultrasound targeting enables improved target volume setup in abdominal tumor radiotherapy
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- Technique can be implemented into clinical routine
- On 4/4/03, 5 cases under treatment at UTHSCSA/CTRC

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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 (Ceha et al., Cancer, 89:2000)
- 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

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, iatrogenic pneumothorax, high frequency jet ventilation

Hepatic metastases – colorectal cancer
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 superimposed 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)

- 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

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Case 1: 4-yr old male, inoperable neuroblastoma
AP/PA 12 Gy bid, IMRT 12 Gy bid (POG 9341) after chemo

Case 2: 75 yrs, male
Inop. pancreatic ca
Case 1: 4-yrs old male, inoperable neuroblastoma
AP/PA 12 Gy bid, IMRT 12 Gy bid (POG 9341) after chemo

Case 3
45 yrs, male
HCC

Case 2:
75 yrs, male
Inop. pancreatic ca

Case 3
45 yrs, male
HCC
Liver metastasis breast cancer

Neuroendocrine liver tumor

07/11/2001

08/03/2001

08/11/2001
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**

![Histograms showing magnitude of residual setup error for all users, experienced users, and inexperienced users.]

**Percent change in setup error**

![Box plots showing percent change in setup error for experienced and inexperienced users.]

- Experienced
- Inexperienced

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44