On-Board Imaging System: Implementation and Quality Assurance Procedures

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- Physicians, residents, therapists, and physicists at *Henry Ford health System*
Presentation Outline

- On-Board Imaging (OBI) System as IGRT Tool
- Clinical Implementation of OBI
- Suggested QA Procedures for OBI and Cone Beam CT (CBCT)
- Summary
IGRT and IMRT

- Clinical use of IMRT requires precise localization of both target and normal tissues at the planning and treatment stages.

- Image Guided RT (IGRT) is targeting the tumor using images with patient in treatment position immediately prior to or during treatment.

- Goal of IGRT is to manage inter- and intra-fraction motion to reduce margins and optimize treatment designs.
Benefit of Image guided radiation therapy (IGRT)

- **Interfractional motion:**
  - The change in target position from one fraction to another (setup error, and target motion)

- **Intrafractional motion:**
  - The change in target position during treatment (target motion, and patient motion)
IGRT Strategies

- **On-line approach**
  making adjustment to the treatment parameters or position based on data within the current txt session

- **Off-line approach**
  Intervention is the result of accumulation of data drawn from txt sessions
IGRT Approaches

- Film imaging acquired using conventional port films
- Electronic Imaging using EPID
- Video & surface Guided
- Digital Projection Imaging (Radiographic and fluoroscopic)
- CT Guided (Cone Beam CT, CT-on rails, MV CT)
- 4D (gating, tracking, breath hold)
- Marker localization and marker Tracking (seeds, coils, infrared, clips, electromagnetic beacons)
IGRT Tools at Henry Ford Health System
Picture shown a 3D video system, BrainLAB infrared Tracking, and Resonant US-sim in CT room.
Identification of a suitable imaging IGRT tool

- Compromise of clinical objectives, product availability, existing infrastructure, and manpower
  - Clinical objectives (dose escalation/normal tissue sparing)
  - Structures of interest (target/surrogates)
  - Desired level of precision
  - Method of intervention/correction
  - Available treatment capacity
  - Application for all or some patients
  - Identification of individuals responsible for commissioning, QA, procedures
  - Structure development for responsibility delegation with respect to measurement, analysis, decision, and correction
Flowchart for Initiating IGRT

1. Purchase
2. Acceptance and Commissioning
3. Procedures
4. Clinical Evaluation
5. Implementation

QA Procedures
- Image acquisition
- Analysis
- Intervention
On-Board Imager

Downriver Center for Oncology
HFH Downriver Cancer Center

- Treat 60 patients/day
- ~70% IMRT
- 2 Varian LINACs; 2100C with EPI D & 21EX with OBI
- Integrated solution with Varis 7, Eclipse TPS, and LINACs
- Philips single slice AcQSim large bore CT
Two robotic arms consisting of kilovoltage X-ray source and detector

Can obtain plain radiographs/fluoroscopic or with rotation can obtain cone beam CT images.
Varian OBI / CBCT System – Downriver Center

Linac Console

KVS

MVD

KVD

OBI/C BCT

RPM
OBI Workstation features

- Acquisition of KV images (radio and fluoro mode)
- 2D/2D automatic and manual matching of reference images to pair acquired images
- 2D/2D automatic and manual matching of reference images to pair of KV/MV images with implanted markers
- Qualitative verification of RPM gating using fluoroscopy
- CBCT Acquisition
- 3D/3D automatic and manual images fusion of CBCT to reference 3D images
Data Flow

LINAC Console

LVI

VARIS Treatment

OBI/CBCT

CT Station

Eclipse Station

Network

HFH Main Campus
VARIS/VISION Servers
Commissioning and Acceptance Testing

- Shielding and room design considerations
- Safety and mechanical aspects
- Geometric calibration of systems
- Radiographic and fluoroscopic imaging system performance
- CT image quality
- Database and data transfer integrity
Training

- Just like any other new modality IGRT requires training
- Training of therapists to use OBI properly is the key to a successful launch of an IGRT program
**OBI-1 GRT Capabilities**

- Film imaging acquired using conventional port films
- **Electronic Imaging using EPID**
- Video Guided
- Digital Projection Imaging (Radiographic and fluoroscopic)
- **CT Guided** (Cone Beam CT, CT-on rails, MV CT)
- 4D (gating, tracking, breath hold)
- **Marker localization** and marker Tracking (seeds, coils, infrared, clips, electromagnetic beacons)
How I GRT

- RPM – Respiratory Gating System
- OBI – On Board Imager
- CBCT – Cone Beam CT
RPM

- Track patients’ respiratory motion with external infrared-reflective marker block. Control intra-fraction motion.
- Correlation of internal motion and external motion
- Treatment time is also a consideration
- Time delay
CT time delay

Time delay study of a CT simulator in respiratory gated CT scanning

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In respiratory-gated radiotherapy (RGRT), if the time delay in a computed tomography (CT) simulator and that in a linear accelerator (Linac) are different, the simulation and the treatment cannot be synchronized. In this study, we presented a technique to measure the time delay of the AcQSim CT simulator (Philips Medical Systems, Cleveland, OH) using Varian’s Real-Time Positioning Management (RPM) system (Varian Medical Systems, Palo Alto, CA). A respiratory gating platform (REF 91150, Standard Imaging, Inc., Middleton, WI) was first set at the position of amplitude maximum (phase 0). Then a ball of 1.3 cm diameter was put on the platform and set at the CT laser. A single axial scan was acquired across the center of the ball without motion. Then the motion was turned on and single axial scans gated at different phases were acquired with a very narrow gating
**ITV Delineation with 4 phases gated CT**

(a) Exhale, (b) Midphase, (c) Inhale, (d) Spiral

ITV encompassing all the visible targets in different phases
Orthogonal portal images – MV and kV image can be acquired without gantry rotation for AP and Lat online patient setup or KV/KV image pair.

Couch position and angle can be corrected based on the 2D-2D matching between the portal images and DRR.
2D/2D Image Registration

Matching & shifts

KV Lat Image/Lat DRR

MV AP Image/AP DRR
Patient Shifts Data

11 Prostate Patients Data (~2000 OBI data)

- Average translational shifts:
  - Vert: $0.07 \pm 0.65$ cm
  - Lng: $0.20 \pm 0.27$ cm
  - Lat: $0.02 \pm 0.43$ cm
CBCT

- CBCT is capable of acquiring and reconstructing 3D volumetric data in one gantry rotation with the patient in treatment position.
- Verification of target position now can be achieved efficiently and accurately using CT images.
CBCT – Techniques

- 650-700 projections
- 370° gantry rotation
- 65 sec acquisition time
- ~2.5 mins total for acquisition and reconstruction
- Beam angle of 14°
CBCT Acquisition
CBCT: 4-Degree of Freedom

3D/3D Match
SIM CT
CBCT
Shift data
Modes of CBCT Acquisitions

- (A) Full Fan: detector centered 30x40, reconstructed FOV of 24 cm in diameter, 15 cm in C-C extent

- (B) Half Fan: detector shifted by 14.8 cm, FOV=45 cm diameter, 14 cm cm c-c extent

Figure 2 Full-fan mode for a small site, A, and half-fan mode for a large site, B.
Acquisition Modes and Bow-Tie Filters
Clinical Protocol for Prostate Cancer

Treatment Planning

SIM CT Scan

CBCT

CBCT-SIMCT

Patient Setup

Treatment
CBCT for Patient Setup

Sim-CT

1st CBCT

2nd CBCT
CBCT for Patient Setup

Sim-CT

1st CBCT

2nd CBCT
What about dose from CBCT

- 42 fractions for prostate treatment
- It is essential to quantify the dose from daily CBCT
- Our work is to measure dose from CBCT

Accepted for Oral Presentation at the 49th AAPM annual Meeting Orlando, FL
Dose Measurement for CBCT

- Surface and body dose for Rando pelvic phantom and IMRT QA phantom.
- In-vivo skin dose of prostate cancer patients acquiring CBCT using TLDs
- Data from TG-61 Protocol
Phantom dose distribution – AP
Phantom dose distribution – RL
Phantom Dose Distribution

CA Setup

R P L

A

TD Setup

R P L

A
Discussion

Lt Lat dose is always higher than Rt Lat dose

The reason is that KVS always starts from patient’s left and ends at patient’s left

There is overlapping for last 10 acquisition and gantry rotation gets slower at the end but dose rate (i.e., pulse rate) keeps the same
Daily CBCT provides better patient setup but it increases skin and body dose. The dose can range from 150 – 250 cGy for skin and 130–180 cGy for body during the 42 daily fractions delivered for IMRT prostate patients.

Should we consider the CBCT dose as treatment dose?
HU Verification

The accuracy of Hounsfield Units (HU) in CBCT not only affect the accuracy of image matching for patient setup, but also the accuracy of actual dose delivered to patient for two reasons:

(a) the accuracy of delineating the structures in CBCT and

(b) the accuracy of inhomogeneous dose calculation

Accepted for the 49th AAPM Annual Meeting 2006 Orlando, FL
To evaluate the HU accuracy of Varian’s CBCT in Half-Fan mode (half bowtie) and its effect to the accuracy of inhomogenous calculation for dosimetric verification of body sites
Phantoms

IMRT QA Phantom (fixed view)

IMRT QA + CTQC phantom (open view)

Sim-CT Morning QA phantom
The measured HU for each insert in the combined phantom
Demonstration of HU profiles for beam hardening

Sim CT

CBCT
The HU between CBCT and Sim-CT

- The average HU difference between CBCT and Sim-CT is within 20.
- The standard deviation of HU in CBCT is 2 times higher than that in Sim-CT.
- Due to higher beam hardening effect in CBCT, the HU at phantom center is 20 higher than that at edges.
With inhomogeneity correction - Phantom Study

- The DVH difference is from the HU difference alone
- The min dose, max dose, mean dose etc. generally agrees to ~3%
Dose statistics for the 9-beam IMRT plan

For IMRT plans, the dosimetric difference with inhomogeneity correction is also relatively small.

The minimum dose, maximum dose, means dose and median dose for any structure agrees generally within ~2-5%.
Dose distribution comparison of original Sim-CT plan with a CBCT plan of 0.22cm average SSD difference, dose is 4.4% higher at reference point.
Prostate-Margin Reduction?

1st Prize Winner of the Residents MSTRO Competition 2006
Favorable Risk Prostate Cancer

- 78 Gy, usually prescribed to the 95% isodose line, to the prostate and proximal 1 cm seminal vesicles using an IMRT technique.

- PTV consists of CTV + 10 mm expansion except 6 mm posteriorly
Comparison of treatment uncertainties for the posterior border of the prostate and seminal vesicles, before and after correction of systematic error for both organ displacement and set-up error. 1 SD refers to one standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>Prostate posterior border</th>
<th>Seminal vesicles posterior border</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before correction</td>
<td>After correction</td>
</tr>
<tr>
<td>1 SD organ displacement (mm)</td>
<td>3.8</td>
<td>2</td>
</tr>
<tr>
<td>1 SD setup error (mm)</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>1 SD total uncertainty (mm)</td>
<td>4.4</td>
<td>3.4*</td>
</tr>
<tr>
<td>Mean organ displacement (mm)</td>
<td>-1.4</td>
<td>0.0</td>
</tr>
<tr>
<td>93% Confidence limit margin (mm)</td>
<td>8.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Coverage probability for 6 mm margin (%)</td>
<td>85</td>
<td>96</td>
</tr>
</tbody>
</table>

* Includes 2 mm correction uncertainty.
Patients

- Five patients with localized prostate cancer were simulated with CT sim and treated to the prostate and proximal 1 cm seminal vesicles to a dose of 78 Gy.
- Educated regarding empty bladder and empty rectum.
Prior to 30 treatment fractions, a cone beam CT was obtained followed by an orthogonal set of radiographs using the OBI.

Patients were shifted according to image registration between radiographs and simulation DRRs. (Patients were initially aligned to skin marks)
Plans

- All organs of interest were contoured on each cone beam CT scan.
- Using each cone beam CT scan, a coplanar nine field IMRT plan was created using the patient’s treatment position coordinates as isocenter.
- Two separate plans were created one with a 10/6 mm expansion and a 5/3 mm expansion.
Data Analysis

Prostate

Percent of dose delivered compared to the simulation plan

- D98: 97.20% 96.70%
- D95: 97.40% 97.40%
- Min: 96.40% 92.00%

Legend:
- 10/6
- 5/3
Data Analysis

Seminal Vesicles (proximal 1cm)

<table>
<thead>
<tr>
<th>Percent of dose delivered compared to the simulation plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>D98</td>
</tr>
<tr>
<td>99.60%</td>
</tr>
<tr>
<td>95.80%</td>
</tr>
<tr>
<td>99.60%</td>
</tr>
</tbody>
</table>

Legend:
- **10/6**
- **5/3**
Data Analysis

Rectum DVH

- 10/6 Plan
- 5/3 Plan

Percentage of total dose vs. V40, V50, V60, V65, V70, V75
Margin Reduction - Results

- Our data indicates a 5/3 margin results in a fairly close dose distribution to the 10/6 margin.
- 5/3 margin reduced high dose bladder and rectum volumes by 30-50%
Interobserver Variability Study
3D/3D Image Fusion

A-P Interobserver Manual Fusion Based Upon Bone and ODI
7 observations/patient

C-C Interobserver Manual Fusion Based Upon Bone and ODI
7 observations/patient

R-L Interobserver Manual Fusion Based Upon Bone and ODI
7 observations/patient

Frequency Histogram of Differences Between Manual and Automatic ODI Fusion

Frequency Histogram of Differences Between Manual and Automatic Bone Fusion
Interobserver Variability Study-Results

- Mean shifts (mm) and SDs were:
  - A-P: -0.4±4.2
  - C-C: 1.4±2.4
  - R-L: -0.7±2.3

- Comparing different observers:
  - 69% (C-C), 83% (A-P), 100% (R-L)

Of the observations fall within 1 mm SD for ROI matching:

- 69% (C-C), 75% (A-P), 90% (R-L)

Of the observations fall within 1 mm SD for OOI matching:

Averages (mm) and SDs of the differences between Manual and Automatic Fusion:

<table>
<thead>
<tr>
<th></th>
<th>A-P</th>
<th>C-C</th>
<th>R-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROI</td>
<td>0.5±1.0</td>
<td>1.3±1.0</td>
<td>0.5±0.6</td>
</tr>
<tr>
<td>OOI</td>
<td>0.6±1.0</td>
<td>0.3±1.5</td>
<td>0.8±0.7</td>
</tr>
</tbody>
</table>
Intensity based 3D/3D Fusion

- **ROI**
  - Rectangular and irregular mask ROI

- **Similarity Measure**
  - MI – Mutual Information
  - NCC – Normalize Cross Correlation
  - EOD – Entropy of Difference
  - GC – Gradient Correlation
  - GD – Gradient Difference
  - PI – Pattern Intensity
  - CR – Correlation Ratio

- **Transformation**
  - Rigid Body Transformations
    - Translation (3D)
    - Translation (3D) + Table Rotation
    - Translation (3D) + Rotation(3D)
  - Affine Transformations
    - Shearing + Rotation + Translation
    - Scaling + Shearing + Rotation + Translation

- **Optimization**
  - Downhill Simplex
Prostate Localization

- **Pelvic bone matching**
  - A rectangular ROI is defined around pelvic bone (excluding femur bones) on either sim or cbct.
  - Similarity measure MI works very well for bone matching.
  - Typically 100 iterations is enough (less than 5 sec on 3GHz CPU)

- **Prostate matching**
  - An irregular mask ROI is defined around prostate and seminal vesicles on the sim CT.
  - Similarity measure GC works the best from experiments.
  - Typically 100 iterations is enough (less than 5 sec on 3GHz CPU)
  - If the prostate boundary is blurry or if there is prominent rectum gas pockets, registration may fail.

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Fusion:

Bone Matching

Click each image to start and stop animation.
- IS OBI sufficient for Prostate localization?
- OBI and margin reduction?
Automatic pelvic bone matching vs. prostate matching

<table>
<thead>
<tr>
<th>Bone Fz</th>
<th>Prostate Fz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~1</td>
<td>13</td>
</tr>
<tr>
<td>1~2</td>
<td>66</td>
</tr>
<tr>
<td>2~3</td>
<td>44</td>
</tr>
<tr>
<td>3~4</td>
<td>33</td>
</tr>
<tr>
<td>4~5</td>
<td>17</td>
</tr>
<tr>
<td>5~6</td>
<td>2</td>
</tr>
<tr>
<td>6~7</td>
<td>4</td>
</tr>
<tr>
<td>7~8</td>
<td>8</td>
</tr>
<tr>
<td>8~9</td>
<td>4</td>
</tr>
<tr>
<td>9~</td>
<td>5</td>
</tr>
<tr>
<td>0~1</td>
<td>33</td>
</tr>
<tr>
<td>1~2</td>
<td>85</td>
</tr>
<tr>
<td>2~3</td>
<td>46</td>
</tr>
<tr>
<td>3~4</td>
<td>27</td>
</tr>
<tr>
<td>4~5</td>
<td>2</td>
</tr>
<tr>
<td>5~6</td>
<td>0</td>
</tr>
<tr>
<td>6~7</td>
<td>0</td>
</tr>
<tr>
<td>7~8</td>
<td>0</td>
</tr>
<tr>
<td>8~9</td>
<td>0</td>
</tr>
<tr>
<td>9~</td>
<td>3</td>
</tr>
</tbody>
</table>
Comments on the three failures

- Case 1: I forgot identifying the calcification points by mistake. Registration was successful (visual confirmation)
- Case 2: the patient was large and the prostate boundary was not clear. Registration failed.
- Case 3: there was a rectum gas pocket near the target. Registration failed.
IGRT/OBI QA Procedures

- QA program to maintain and monitor system performance characteristics established at the time of commissioning

- QA Program should include
  1. Safety and functionality of the system
  2. Geometry
  3. Image quality
  4. Database and data transfer integrity
Figure 3 (a) Cube phantom with 1 fiducial marker at the center of the cube, (b) printed circuit board and (c) marker block with 1 fiducial marker at the center and 4 disks inside of the block.
Daily QA procedure checks the geometric accuracy of the OBI system by performing the following tests:

- **Test 1:** Tube/detector positioning accuracy
  Assures that the imagers (MVD & KVS/KVD) isocenter matches the LINAC isocenter

- **Test 2:** Matching and couch motion accuracy
  Positional differences detected by the OBI workstation can be reliably transferred to couch motion
The Cube Isocenter Phantom provided by Varian was used for this daily QA procedure.

Two sets of 1.5-mm lead shots (bbs) were used to define 2 separate spatial locations (points.)

In each set, one bb is on the anterior side (AP bb) and the other (Lat bb) is on the lateral side of the phantom.

The first set defines the isocenter (at the phantom center) and the second set defines a point 1.5 cm anterior, inferior, and lateral from the isocenter.
The OBI daily QA procedure starts with setting up the Cube phantom center (central bb set) at the mechanical isocenter of the linac by using the cross hairs projections anterioely and laterally.
Using the plan created from *Eclipse*, AP MV (or KV) and Lat KV images were acquired (*shown only Lat image*)
The alignment of the central bbs with the digital graticule (representing the imager isocenter) will be checked from both AP and Lat images.
3 translational shifts between the center of the graticule and the center of the bbs were measured and tabulated
MV Isocenter Check

Daily mismatch distance (mm)

Daily measurement (days)

S/I
R/L
OBI: Daily QA- Test 1

KV Isocenter Check

Daily mismatch distance (mm)

Daily Measurement (days)

S/I
A/P
OBI Isocenter Accuracy QA
If test 1 is acceptable, the DRRs (AP & Lat) were moved to overlay on the off-axis bb of the images.
The shifts obtained will be applied to remotely move the couch. The shifts and the new couch positions will be recorded.

|     | A         | B         | \(|A-B| \leq 0.2\) |
|-----|-----------|-----------|-----------------|
| New couch | 11.9  | 116.4  | 3.7  |
| Shift | 1.6  | 1.6  | 1.5  |
Cross hairs projected from the linac should cross the off-axis bb set on the phantom

Manual couch motion might be needed to assure the overlay of the cross hairs and the center of the off-axis bb set

Final couch positions will be recorded. The difference between the final and new couch positions should be within 2 mm
Results: 2D/2D match
The suggested QA tests assure reliable portal images for verification of daily patient positioning.

The procedure is simple and easy to implement. It takes about 10 minutes to do the QA.

Accuracy the procedure can detect is better than 2mm.
The monthly QA procedure includes isocenter accuracy over gantry rotation, checking collision interlock, mechanical center check, center reproducibility, digital measurement, and image quality of MVD, KVS and KVD
OBI isocenter accuracy over gantry rotation

- Acquiring KV images over multi gantry rotations
- Shown @ 4 gantry angles
Results-Gantry ISocentricity

Average Vector Displacement (mm)

Gantry 0
Gantry 90
Gantry 180
Gantry 270

Feb
Mar
Apr
May

Date
Safety QA-Collision Interlocks

<table>
<thead>
<tr>
<th></th>
<th>MVD</th>
<th>KVS</th>
<th>KVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm pedal</td>
<td>Alarm sound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device body</td>
<td>Alarm sound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gantry motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Couch motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBI console</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OBI Safety and functionality QA

- Tube warm up
- Door interlock
- Warning lights
- Storage space availability
- Database integrity
1. Mechanical Center Check:
   - Measure distance between MVD cover @ (0,0,150) and isocenter
   - Measure offset between the mark and the crosshairs projected from Linac

<table>
<thead>
<tr>
<th>Reading (cm)</th>
<th>Distance</th>
<th>S/I (longitudinal) shift</th>
<th>R/L (lateral) shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected value (cm)</td>
<td>47.2 ± 0.2</td>
<td>≤ 0.2</td>
<td>≤ 0.2</td>
</tr>
</tbody>
</table>

   - Run-out during arm vertical travel with MVD @ (0,0,130)
   - Measure offset between the mark and the crosshair projected from Linac

<table>
<thead>
<tr>
<th>Reading (cm) shift</th>
<th>S/I (longitudinal) shift</th>
<th>R/L (lateral) shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected value (cm)</td>
<td>≤ 0.2</td>
<td>≤ 0.2</td>
</tr>
</tbody>
</table>
Mechanical QA (MVD)

- Digital Measurement Accuracy:
  Place blade calibration tool @ isocenter, acquire MV image.
  Using measuring tool from OBI to measure S/I R/L length of 10cm x 10cm square.

<table>
<thead>
<tr>
<th>Reading (cm)</th>
<th>Expected value (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/I (vertical) line</td>
<td>10.0 ± 0.2</td>
</tr>
<tr>
<td>R/L (horizontal) line</td>
<td>10.0 ± 0.2</td>
</tr>
</tbody>
</table>
Mechanical Center Check:

- Rotate gantry @ 90° so that KVD @ (0,0,150) is on the Floor
  - Measure distance between grid surface and Isocenter
  - Measure offset between the mark and laser projected from ceiling

<table>
<thead>
<tr>
<th>Reading (cm) Expected value (cm)</th>
<th>S/I (longitudinal) shift</th>
<th>R/L (lateral) shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.2</td>
<td>≤ 0.2</td>
<td></td>
</tr>
</tbody>
</table>

- Run-out during arm vertical travel with KVD @ (0,0,130)
  Measure offset between the mark and laser projected from ceiling

<table>
<thead>
<tr>
<th>Reading (cm) Expected value (cm)</th>
<th>Distance S/I (longitudinal) shift</th>
<th>R/L (lateral) shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.2 ± 0.2</td>
<td>≤ 0.2</td>
<td>≤ 0.2</td>
</tr>
</tbody>
</table>
1. Mechanical Center Check:
Rotate gantry @ 270° so that KVS @ (0,0,100) is on the floor
• Measure distance between KVS plate and isocenter
• Measure offset between the mark and laser projected from ceiling

<table>
<thead>
<tr>
<th>Reading (cm)</th>
<th>Distance</th>
<th>S/I (longitudinal) shift</th>
<th>R/L (lateral) shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected value (cm)</td>
<td>85.2 ± 0.2</td>
<td>≤ 0.2</td>
<td>≤ 0.2</td>
</tr>
</tbody>
</table>
Results

KVD & KVS mechanical displacement over 1 year period
To establish baseline for image quality parameters and to monitor these parameters over time

Adopted tests from conventional QA programs for radiographic units
Image Quality (MVD)

Set MVD @ (0,0,150) and place the *Vegas Phantom* on the top of MVD.

- Acquire MV high quality image
- The max R visible in C1 determines contrast, and the max C visible in R1 determines resolution
Image Quality (KVS/ KVD)

Set KVD @ (0,0,150) and place the Leeds Phantom TOR 18FG on the top of KVD.

18 disks of 8 mm diameter each with contrast ranging between 16.7% and 0.9% and central 21 bar patterns ranging between 0.5 to 5 lp/mm

- **Contrast:** Acquire single high quality image and fluoroscopic mode ~(70 kVp, 25 mA, 6 ms) with 1 mm copper plate over KVS.
  The number of visible disks along the rim determines the contrast.
  11 (3.2%) or 12 (2.7%) contrast disks or more should be discernable.

- **Spatial Resolution:** Take a KV radiographic and fluoroscopic exposure ~(50 kVp, 80 mA, 32 ms).
  Select the smallest visible group of line pairs.
  11th group of bars, equivalent to 1.6 lp/mm should be visible.
CBCT QA

- Didn’t include a separate geometric measurement for CBCT images
- Geometry of KV radiographs and CBCT images depend upon the position of the OBI arms
CBCT Image quality

- QA tests adopted from diagnostic CT scanners
- Alternate check of full-fan and half-fan modes
- Use the Catphan 504 phantom
- Scan acquired 125 kVp, 80 mA, 25 ms 150 SID with 512x512 reconstruction matrix and 2.5 mm slice thickness
HU Accuracy

- CTP 404 inserts contains 7 materials of different densities
- Using ROI 0.7x0.7 cm
- HU values should be within 40 HU
## HU Accuracy - OBI 1.3

<table>
<thead>
<tr>
<th></th>
<th>Expected HU</th>
<th>Full-Fan</th>
<th>Half-Fan</th>
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<tr>
<td></td>
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<td>Measured HU</td>
<td>Diff.</td>
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<tr>
<td><strong>Tolerance</strong></td>
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<td>&lt;±40</td>
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Low Contrast Resolution

- CTP 515 insert 3 groups of supraslice disks with diameters ranging from 2-15 mm and subject contrasts of 1%, 0.5%, and 0.3%

- Recommendation 1%, 7 mm disk
CTP 528 insert contains a spatial resolution rule with bar patterns between 1 to 21 lp/cm.

Recommendation 6lp/cm
HU Uniformity

- CTP 486 insert is a uniform disk of 20 cm diameter
- Area profile used 5 ROIs
- Within 40 HUs
Summary

- The complex nature of the radiation therapy process and the need to produce a patient specific treatment that maximizes the therapeutic ratio requires “proper” integration of IGRT systems into the process.

- This requires significant effort to implement and to employ.
Summary

- OBI is one of these systems designed to correct for motion and setup errors of patients.

- We presented a QA program to monitor the mechanical and image quality of the system.

- The tests use tools and phantoms provided with the OBI system.

- Since OBI is a device to improve geometric accuracy of patient treatments, the most critical tests are those of its mechanical stability/accuracy.
Summary

- Measurements show that mechanical stability of the OBI system is quite high with SD of 0.3 to 0.4 mm over 1 year period monitored by the geometric positioning of the arms.

- Tests were useful in detecting performance deficits.

- Implementation of QA tests, methods, frequency, and tolerances could vary. However, it's important to establish a guideline.
Summary

- More work should be done on improving image quality
- Smooth flow of data
- More work on automatic fusion
Thank You