Comparison of Two Phantoms for End-to-End SRS/SBRT Testing

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Disclosure

- Travel and Speaker Honorarium from Sun Nuclear Corp.
Overview

- Comparing the two phantoms on different aspects of end-to-end testing
- Lessons Learned and Tips/Tricks for using the phantoms
- The “joys” of micro chambers (time permitting)
The nature of SRS/SBRT requires very high accuracy both on the planning end and on the delivery end.

Much has been written about the special requirements for characterizing beams used for stereotactic treatments.

A large body of literature also exists on how to test various aspects of the SRS/SBRT treatment chain.
QA for SRS/SBRT

- The end-to-end (E2E) test is the only test that can tell us the whole story about our accuracy.

- This is why the E2E test should be done regularly (recommendation of TG101).

- Is there a phantom that would allow us to do this efficiently?
What would constitute an ideal phantom?

- Easy to set up.
- Reproducible setup.
- Allows user to do a full E2E.
Current Commercial Solutions

- **Non-anthropomorphic**
  - The Lucy 3D QA Phantom (Standard Imaging)
  - StereoPHAN (Sun Nuclear)

- **Anthropomorphic**
  - STEEV (CIRS)
  - Max-HD (IMT)

Lucy  | StereoPHAN  | STEEV  | Max-HD
--- | --- | --- | ---
[Image of Lucy phantom] | [Image of StereoPHAN] | [Image of STEEV phantom] | [Image of Max-HD]

www.medicaldevice depot.com  www.gammagurus.com
The Two Candidates

- **Lucy 3D QA & StereoPHAN**
  - Both are non-anthropomorphic
  - Both are precision-milled
  - Both are modular
  - Both are meant to be used for E2E testing
  - Lucy has been in the market for a very long time while StereoPHAN is newer.
  - Do they fit the “ideal phantom” characteristics?
Ease of Setup

1. Disassembly required to change inserts
2. Smooth clear surface
3. Roughly 5 mins to change insert and reposition using lasers

1. No disassembly required to change insert
2. Matte surface
3. Roughly 2 mins to change insert and reposition using lasers

Once a user gets familiar with the phantoms, they are both easy to use and are basically equivalent.
An ideal phantom?

- Easy to set up.
  - Reproducible setup.
  - Allows user to do a full E2E.
Repositioning Reliability Test

- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.
Repositioning Reliability Test

- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.
Repositioning Reliability Test

- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.
Repositioning Reliability Test

- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.

- The test was repeated 5 times by a single user (intra-user) and then by three different users (inter-user).

- Done in 3 clinical scenarios:
  1. Framed (Brainlab) with no IGRT
  2. Frameless with ExacTrac IGRT
  3. Frameless with kV Conebeam CT IGRT
Repositioning Reliability Test
Framed, No IGRT
Repositioning Reliability Test
Frameless, ExacTrac IGRT
Repositioning Reliability Test
Frameless, Conebeam CT IGRT

Planned Offset

Distance Superior of Center of Film (mm)
Distance Anterior of Center of Film (mm)

Distance Superior of Center of Film (mm)
Distance Left of Center of Film (mm)
Repositioning Reliability Test Result Summary & Conclusion

- Very tight clustering of results shows reproducibility.
- Results being close to expected value shows accuracy.
- Both phantoms were deemed equivalent as far as repositioning reliability
  - … but there were some lessons learned along the way
Lessons learned

- Both phantoms made of uniform material with very few elements to provide image contrast.

- It therefore makes it imperative that the reference CT scan used for IGRT be obtained in the exact geometry in which the phantom is being imaged.
Reference CT in correct geometry
Reference CT in incorrect geometry
An ideal phantom?

- Easy to set up.
- Reproducible setup.
  - Allows user to do a full E2E.
Phantom End to End Testing

- In the clinic, we would use the full workflow to do our end to end test.

- For a direct comparison, since the phantoms have different geometries, we broke this part down in two parts
  - CT/MRI Fusion
  - A phantom “Plan Validation” test based on a clinical plan
CT/MR Fusion

- Both phantoms provide inserts with objects of known volumes that can be imaged in both an MRI and CT scanner.

- This allows us to check for two properties:
  - How each modality will affect the contoured volumes.
  - How much distortion is being introduced from the MR process.
# Volume Check

<table>
<thead>
<tr>
<th>Lucy</th>
<th>CT</th>
<th>MRI - SPGR (T1)</th>
<th>MRI - T2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual Volume (cc)</td>
<td>Contoured Volume (cc)</td>
<td>Difference (%)</td>
</tr>
<tr>
<td>1.70</td>
<td>1.70</td>
<td>1.81</td>
<td>6%</td>
</tr>
<tr>
<td>5.25</td>
<td>5.25</td>
<td>5.422</td>
<td>3%</td>
</tr>
<tr>
<td>12.25</td>
<td>12.25</td>
<td>12.76</td>
<td>4%</td>
</tr>
</tbody>
</table>

Average: 1% 5% 11%

<table>
<thead>
<tr>
<th>StereoPHAN</th>
<th>CT</th>
<th>MRI - SPGR (T1)</th>
<th>MRI - T2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual Volume (cc)</td>
<td>Contoured Volume (cc)</td>
<td>Difference (%)</td>
</tr>
<tr>
<td>0.52</td>
<td>0.52</td>
<td>0.55</td>
<td>5%</td>
</tr>
<tr>
<td>0.52</td>
<td>0.54</td>
<td>0.56</td>
<td>7%</td>
</tr>
<tr>
<td>3.90</td>
<td>3.90</td>
<td>4.00</td>
<td>3%</td>
</tr>
</tbody>
</table>

Average: 0% 5% 9%
Evaluation of MRI Distortion

- Another way to do this is by using a grid-like insert that can be imaged and show distortions as non-straight lines.
  - Available with Lucy but not StereoPHAN.
End to End – Plan Validation

- Done on a Novalis Classic with a 9-field IMRT plan (Rx = 5 Gy/fraction)
  - Framed using no IGRT
  - Frameless using ExacTrac for IGRT

- Repeated on a TrueBeam using a 2-arc VMAT plan (Rx = 5 Gy/fraction)
  - Frameless using kV CBCT for IGRT
## Plan Validation Results

<table>
<thead>
<tr>
<th>Phantom</th>
<th>IGRT Type</th>
<th>Plan Type</th>
<th>Plan Dose (Gy)</th>
<th>Average Measured Dose (Gy)</th>
<th>Difference from Planned Dose (%)</th>
<th>Difference between Phantoms (%)</th>
<th>Average Gamma (2%,2mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucy Framed</td>
<td>None</td>
<td>9 Field IMRT</td>
<td>5.40</td>
<td>5.38</td>
<td>-0.4%</td>
<td>0.6%</td>
<td>90.0</td>
</tr>
<tr>
<td>StereoPHAN Framed</td>
<td>None</td>
<td>9 Field IMRT</td>
<td>5.22</td>
<td>5.23</td>
<td>0.2%</td>
<td></td>
<td>88.1</td>
</tr>
<tr>
<td>Lucy Frameless</td>
<td>ExacTrac</td>
<td>9 Field IMRT</td>
<td>5.40</td>
<td>5.33</td>
<td>-1.4%</td>
<td>0.1%</td>
<td>84.5</td>
</tr>
<tr>
<td>StereoPHAN Frameless</td>
<td>ExacTrac</td>
<td>9 Field IMRT</td>
<td>5.22</td>
<td>5.15</td>
<td>-1.3%</td>
<td></td>
<td>83.4</td>
</tr>
<tr>
<td>Lucy Frameless</td>
<td>kV CBCT</td>
<td>2 Arc VMAT</td>
<td>5.72</td>
<td>5.78</td>
<td>1.0%</td>
<td>0.4%</td>
<td>98.0</td>
</tr>
<tr>
<td>StereoPHAN Frameless</td>
<td>kV CBCT</td>
<td>2 Arc VMAT</td>
<td>5.59</td>
<td>5.63</td>
<td>0.6%</td>
<td></td>
<td>96.9</td>
</tr>
</tbody>
</table>
An ideal phantom?

✔ Easy to set up.
✔ Reproducible setup.
✔ Allows user to do a full E2E.
Would you like fries with that?

- Lucy offers the following other functionality:
  1. Insert allowing stack of films for a pseudo-3D dose distribution.
  2. MRI Distortion Insert.
  4. Dosimetry Insert for TLD or MOSFET.
  5. 3D Volumetric Target Dosimetry Kit.

- SterePHAN offers:
  1. Cyberknife-specific modules.
  2. 3-Film stack
  3. Ability to use SRS MapCHECK™

- Non-equivalent functionality was not tested.
The results from both phantoms were equivalent for all tests performed.
Lessons Learned

- Scan the phantom in the same geometry as you intend to use it.
Lessons Learned

- Orientation can turn out to be a show stopper. Mark your inserts and always use the same orientation.
Lessons Learned

- If you will use a film insert, use the registration pins to guide you in your analysis.
Lessons Learned

- For “absolute” dose measurements with a micro-chamber, do not use a 10x10 cm$^2$ field as reference.
  - These tend to have a rather large stem effect associated with it.
  - Use a smaller field size (say 3x3 cm$^2$)
- Speaking of micro-chambers…
Background

- Commissioning of a new algorithm required new water scans to be obtained.
- Since very small fields would be involved, a micro-chamber (A16) was used to obtain all of the scans.
- The first set of scans obtained looked normal
  - $d_{\text{max}}$, trend with field size, trend with depth etc…
All was well…

until the 10x10, 100 SSD scan was compared to the analogous one obtained the previous month during the TG-51 calibration using a Farmer chamber.
Background

PDD scans obtained in the Scanditronix/Wellhofer RFA300 water tank

Percent Depth Dose

Depth (mm)

- 0.007 cc
- 0.6 cc
Background

- The scans were repeated using both chambers and found to be reproducible.
- The A16 scan had been done with a +300V bias.
  - Historically, we have always had our chambers calibrated at this bias.
- So we decided to switch biases and see the effect.
Background
Questions

- Is it related to
  - Our A16 chamber?
    - Repeat with multiple A16 with our water tank – phone a friend
  - Chamber size?
    - Repeat with multiple chambers and same water tank – we have plenty
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber) – phone a friend
Multiple versions of same chamber model (A16)
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water
  - Chamber size?
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)
Scanning with chambers of differing active volumes

PDD scans obtained in the Scanditronix/Wellhofer RFA300 water tank

- PTW N30013
  - 0.6 cc, -300V
  - 0.6 cc, +300V
- PTW 31013
  - 0.3 cc, -300V
  - 0.3 cc, +300V
- PTW 31010
  - 0.125 cc, -300V
  - 0.125 cc, +300V
- Exradin A1
  - 0.053 cc, -300V
  - 0.053 cc, +300V
- Wellhofer IC04
  - 0.04 cc, -300V
  - 0.04 cc, +300V
- Exradin A16
  - 0.007 cc, -300V
  - 0.007 cc, +300V
Scanning with chambers of differing active volumes
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes. Due to large $P_{pol}$?
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)
Unusually large $P_{\text{pol}}$?

<table>
<thead>
<tr>
<th>Chamber</th>
<th>$P_{\text{pol}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A16 #1</td>
<td>1.009091</td>
</tr>
<tr>
<td>A16 #2</td>
<td>1.011544</td>
</tr>
<tr>
<td>CC04</td>
<td>1.010345</td>
</tr>
<tr>
<td>A1</td>
<td>1.006695</td>
</tr>
<tr>
<td>PTW 31010</td>
<td>1.00655</td>
</tr>
<tr>
<td>PTW 31013</td>
<td>1.000325</td>
</tr>
<tr>
<td>PTW N30013</td>
<td>1.000162</td>
</tr>
</tbody>
</table>
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes. Due to large $P_{pol}$?
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)
Using with multiple scanner systems

Scanditronix Tank/RFA300 Controller

- A16, -300V
- A16, +300V
- PTW31010, -300V
- PTW31010, +300V

Percent Depth Dose vs Depth (mm)
Using with multiple scanner systems

Blue Phantom 2 Tank/CU500E Controller

% Depth Dose vs Depth (mm)

- A16, -300V
- A16, +300V
- CC13, -300V
- CC13, +300V
Using with multiple scanner systems

Standard Imaging DoseView 3D Tank/DoseView 3D Electrometer

Percent Depth Dose

Depth (mm)

- A16, -300V
- A16, +300V
- A28, -300V
- A28, +300V
Using with multiple scanner systems
Using with multiple scanner systems

Scanditronix Tank/RFA300 Controller

Blue Phantom 2 Tank/CU500E Controller

Standard Imaging DoseView 3D Tank/DoseView 3D Electrometer

PTW MP3-M Tank/PTW Tandem T10015 Controller
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination? Yes
    - Repeat with multiple water tanks (same chamber)
Updated Questions

- Is it related to
  - Our A16 chamber? No
  - Chamber size? Yes
  - Our water tank/chamber combination? Yes
  - Our process in general?
    - Is this related to the scanning process? How about sampling the PDDs instead of dynamically acquiring them?
Sampling the PDD with internal and external electrometer

PDD data, in Scanditronix/Wellhofer, using A16 chamber, 6MV flat beam, statically and dynamically acquired, using Internal and External electrometers

-300V Dynamically Scanned
+300V Dynamically Scanned
-300V Static Internal Electrometer
+300V Static Internal Electrometer
-300V Static k602
+300V Static k602
-300V Static Max4000
+300V Static Max4000
More questions

- Is this effect observed with
  - All energies?
  - Profiles as well as PDDs?
- Is the effect related to
  - Electronic noise in the system?
  - Charge vs Current?
PDDs using different energies

- **6X**: Difference = 4.7%
- **10X**: Difference = 4.1%
- **6FFF**: Difference = 2.9%
- **10FFF**: Difference = 3.9%
More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes

- Is the effect related to
  - Electronic noise in the system?
  - Charge vs Current?
Electronic Noise

- Using raw ADC signal levels from the water tank software (OmniPro)
  - There is some noise seen as the motors are run and no beam is turned on – of the order of 1% of signal at 30 cm.
- The same is observed when using an external electrometer (CNMC K602) to measure currents.
More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes

- Is the effect related to
  - Electronic noise in the system? Does not seems so
  - Charge vs Current?
## Charge vs Current

<table>
<thead>
<tr>
<th>Measurement Technique</th>
<th>Tank ADC units</th>
<th>External Electrometer Current (pA)</th>
<th>External Electrometer Charge (nC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PDD\textsubscript{20}</td>
<td>PDD\textsubscript{25}</td>
</tr>
<tr>
<td>Bias (V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-300</td>
<td></td>
<td>37.4%</td>
<td>28.7%</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td>41.5%</td>
<td>32.4%</td>
</tr>
</tbody>
</table>
More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes
- Is the effect related to
  - Electronic noise in the system? Does not seems so
  - Charge vs Current? Same results – at least for static measurements with an independent electrometer
What we learned

- The effect
  - Causes non-trivial over-estimation of the PDD when a very small chamber is used under specific conditions.
  - Is reproducible for multiple versions of the same chamber.
  - Is seen with at least three scanner systems.
  - Seems to go away when an external electrometer is used.
  - Does not always occur at the same bias.
What we learned

The effect

- Does not seem to be solely due to larger than normal $P_{pol}$ in some chambers.
- Is seen with different energies and the tail of profiles (lower signal levels).
- Does not seem to be relatable to noise in the scanning system.
- Does not seem to be related to measuring current vs charge.
Our conclusion

- We do not have a definite explanation for why the effect occurs.
- We know the effect exists and can lead to commissioning errors.
  - Due to the rather insidious presentation of the error.
- We have a **clinical recommendation**: Anyone using a micro chamber during scanning should check their scans against one obtained using a larger chamber to determine which bias to use.
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Questions