QA in Advanced Technique

to Address the Needs in Rapidly Changing World of Radiation Therapy

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THAILAND, 12-2012.

CONFLICT OF INTEREST DISCLOSURE:

My travel expenses to this conference has been supported by Varian Medical Systems.

Other than that, neither myself or my family have any financial interests in Varian Medical Systems.

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First, let us review the following relatively “new” practices in radiation therapy:

“New” clinical practices:
1. Hypofractionated radiation therapy
2. Stereotactic Body Radiation Therapy (SBRT)

“New” treatment delivery techniques:
3. IMRT (now 15 years old)
4. VMAT (now 6 years old)
5. Flattening Filter Free (FFF) X-ray beams

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Riding the wave of CHANGE in CLINICAL PRACTICES, the role of medical physicists are also evolving at a fast pace.

The most evident is the requirement of acquiring new acknowledge about the practice, the equipment, and the PATIENT.

And, more than ever before, clinicians are seeking advices from their physicist colleagues; especially, in term of patient treatment techniques.

Physicists should be equipped and ready to make “go” or “no go” decisions on the spot.

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Physicists are now involved in many “non-traditional” tasks in daily XRT patient management, for example:

Traditional tasks:
- Equipment calibration and QA
- Equipment purchase evaluations
- Treatment chart reviews
- Occasional XRT setup monitoring and assistance
- Dosimetry and pre-treatment QAs
- First line “Go-To” person when problems occur

Non-traditional tasks:
- Image fusion (in US, it must be done by physicists)
- Advise on an appropriate mode of XRT for patients
- Diagnostic imaging issues (e.g.: for better kV/CBCT pictures)
- Organ motion management (breath-hold, gating)

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Therefore:

I would like to expand and to divide the topic of QA into the following 2 categories:

1. Clinical QA in radiation therapy
2. Physics (technical and instrumentation) QA
(1) Clinical QA in radiation therapy:
- target localization margins
- motion management
- patient safety (a separate discussion)
  (during the next AOCMP, maybe?)

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Definition:
SBRT (SABR) =>
Stereotactic Body Radiation Therapy (fixation, localization, image guidance, motion management)

Hypofractionation =>
Using fewer than "normal" number of treatment fractions
And, generally, much higher doses per fraction
(50 Gy / 5) (48 Gy / 4) (60 Gy / 3) (38 Gy / 5) (24 Gy / 1) (8 Gy / 1)

To have successful hypofractionated treatments, a good SBRT program is necessary. Of course, QA procedures must be in place for high dose deliveries.

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Recent examples of hypofractionation in the literature
- The Canadian 42.5 Gy in 16 fractions and UK 39-42 Gy in 13 fractions breast trials
- The 25 Gy in 5 fractions Swedish and Dutch pre-op rectal trial
- The 17 Gy in 2 fraction palliative lung trial
- The 8 Gy in 1 fraction for bone metastasis
- The 24 Gy in 1 fraction for pancreatic cancer
- The 20 Gy in 3 fractions in 1 1/2 weeks RTOG-0236 lung trial
- The 24 Gy in 1 fraction for pancreatic head
  (and many other hypofractionation schedules and doses)
- Now, HYPOFRACTIONATED TREATMENTS of prostate cancers

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IGRT paves the way for hypofractionation
- We treat most of our patients with on-line IGRT since April, 2004.
- We treated our first patient (NSCLC) in 2004.st hypofractionated
- We treated first patient with CBCT guidance in September, 2005.
  - Think of IGRT as a "QA" of the patient setup.
- IGRT clearly increases treatment accuracy.
- Better accuracy leads to smaller PTV margins.
- Smaller PTV margins allow less normal tissue exposure and novel fractionation schemes and/or doses ! But, beware of TARGET MISS. Target miss is the worst type of "treatment complications". And, it the most expensive both in money and human costs.

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Precision vs. accuracy: IMRT (precise) vs. IGRT (accurate)

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Hypo-fractionation
- Is not a new concept nor is a new treatment technique
- Gain recent popularity because of:
  - the ability to deliver conformal doses to target and to spare neighboring normal tissues with IMRT.
  - the ability to place the intended target within the high dose volume with IGRT.
  - the ability to deliver a high dose within a short time with high dose rate (high MU/minute) capability on modern linear accelerators (e.g.: with FFF beams).

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**Pre-requisites of hypo-fractionation**

- Position the target inside the high dose volume for every treatment
  - Must have image guidance (X-ray pair, CBCT)
- Patient and Organ motion management
  - Must take breathing into consideration (breath-hold, gating, free-breathing with appropriate margins for planning)
- Treatment duration
  - Must take the dose rate into consideration (patient motion and/or radiobiological concerns)
- A very reliable treatment machine
  - No one knows what to do with an interrupted hypofractionated treatment.

**3 key issues in executing hypofractionated lung treatments**

**Motion**
- Gating (~50% patients) for good cyclical breathers
- And, one should consider breath-hold (usually works better than gating – but needs practice)

**Margin**
- Larger (~9-10 mm for non-gating)
- Smaller (5-7 mm for gating)
- Toxicity reduction is the goal but TARGET MISS is a real KILLER.
  - Consider the concept of "minimum margin" (If there is no gain in toxicity reduction, why risk target miss by applying unreasonable narrow margins around GTV ?)

**Setup**
- CBCT on every patient needing soft tissue match
  - Immobilization... fixation...

There is a definite trade-off between margins around GTV vs. treatment toxicity vs. probability of target miss

**The purpose of IMRT or VMAT:**

- is to create a high dose volume with excellent conformity (normal tissue sparing).

**SBRT**:
- However, when one is dealing with treatments with LARGE MUs (long treatment time) and only a FEW FRACTIONS, there are other factors to be considered ... :

**2 different SBRT delivery philosophies**:

(1) Some clinicians use IMRT or VMAT to achieve target dose uniformity and normal tissue sparing.

(2) However, some other clinicians have concerns about using IMRT or VMAT in lung lesions (SBRT of lung) because of organ motion. 3-D conformal plans with 10+ fields are used. In these cases, clinicians are willing to accept large target dose inhomogeneity (dose gradient) within the PTV. With Varian TrueBEAM, the "super-beam" automation dramatically shorten the treatment time.

**In both cases, organ motion concerns are managed by RPM gating or breath-hold.**

I will use this example to compare 3 different methods to deliver a large dose (per fraction) to a target volume :

- 3-D conformal plan with 11 fields
- 10-field IMRT plan
- 2-arc VMAT plan
Comparison of lung SBRT plans: 3-D conformal vs. IMRT

Note: Both plans are tightly conforming to the PTV. 3-D conformal plan has a much larger hot-spot inside the PTV (covering the GTV in this case). The IMRT plan has a better dose homogeneity index inside the PTV. But, is this important in SBRT? No difference in normal tissues dose.

Plan dose statistics

**IMRT plan**
- PTV prescription 4800
- Volume max. dose 5551
- PTV max. dose 5551
- PTV min. dose 3921
- PTV mean dose 5145

**3-D plan**
- PTV prescription 4800
- Volume max. dose 6487
- PTV max. dose 6487
- PTV min. dose 3771
- PTV mean dose 5639

Other factors to be considered:
(1) Effects of combined movements between organ and MLC leaves in IMRT
(2) IMRT plan has 250% more MUs (treatment time is almost 4 times longer)

**IMRT**
- Prescription: 4800 cGy in 4 fractions
- IMRT MUs: total 6291
- 15.7 min. beam on time
- @ 400 MU/minute

**3-D**
- Prescription: 4800 cGy in 4 fractions
- 3-D MUs: total 2522
- 2.6 min. beam on time
- @ 1000 MU/minute

Q: What can VMAT perform under these conditions?

**IMRT**
- Prescription: 4800 cGy in 4 fractions

**VMAT**
- Prescription: 4800 cGy in 4 fractions

Other factors to be considered (continue):
(1) VMAT => Effects from combined movements with organ and MLC leaves
(2) MUs (1411) for VMAT plan is about half of the 3-D plan (treatment time is less than 2 minutes for this 2-arc VMAT plan)

In addition, at MIMA Cancer Center, . . .

We often use couch angulations for the 2-arc VMAT plan. For patient safety reasons, it would be necessary for our therapists to enter the treatment room between the 2 arcs to move the treatment couch (though the Varian machine is capable of moving the couch from outside the treatment room).

This would definitely lengthen the “treatment time”.

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The purpose of IGRT:

is to place the clinical target in the high dose volume, fraction after fraction, day after day. And, we use the most efficient and effective method to achieve this purpose; which may be:

- $kV$ X-ray pairs
- cone beam CTs
- some other imaging devices.

Think of IGRT is the ultimate QA for radiation therapy of a particular patient.

A modern linear accelerator for radiation therapy:

1. $kV$ imaging system
2. MV imaging system
3. High dose and dose rate deliveries
4. OBI compatible couch top
5. Patient immobilization devices
6. Organ motion management.

ITV is defined by drawing a new GTV to enclose all GTVs from all 4 simulation CTs; then, add a margin (3 to 7 mm) to this ITV to form a PTV. Prescription is to cover this PTV.

For hypofractionated radiation therapy:

One must place the clinical target into the conformal, high radiation dose volume for every fraction.

Because of high doses and few fractions, target miss during XRT (even during a single fraction) could be devastating.

One must keep MARGIN around the GTV in mind when designing the PTV. Most devastating treatment complication is TARGET MISS.
Position the target inside the high dose volume for every treatment
- Use CBCT for image guidance (CBCT can be used with breath-hold technique but not gating at this time)

Motion management
- Most often, we use *breath-hold* technique. But if the patient is not cooperative, we use larger margins around the GTV to form the PTV. And, we monitor the patient motion during treatment with skin markers placed on the patient skin and view the markers via CCTV – a simple but effective method.

Hypofractionation of abdominal lesions with VMAT

Using CBCT to align soft tissue targets for hypofractionated treatment

Isodose on CBCT

Isodose on matched GECT and CBCT images displayed in "blend" mode

CBCT images matched to the reference CT image

Using CBCT to align soft tissue targets for treatment

CT - PET

Approximately 1 cm proximal to the GE junction lesions and heart
Hypofractionation of early stage lung lesions with SBRT (SABR) for non-surgical candidates

SBRT doses:
(Be careful of what you read in the literature)
RTOG 0236 (inoperable, peripheral) => 60 Gy in 3 fx (95% of PTV).
JCOG 0403 => 48 Gy in 4 fx. (at isocenter)
Chang => 50 Gy in 4 fx. (PTV)
Stephans => 50 Gy in 5 fx.
Blaumann => 45 Gy in 3 fx. (67% isodose line at margin)
Yamashita => 48 Gy in 4 fx.
Barriger => 54 – 66 Gy in 3 fx.
Central location => 60 Gy in 8 fx.
Peripheral location => 60 Gy in 3 fx.
RTOG 0813 (for central location) => 50 – 60 Gy in 5 fx.
Recently open RTOG 1021 Phase 3 (for high risk operable, centrally located targets)

Image guidance:
If one wishes to use CBCT to localize (lung) targets, first, we should review the capability of CBCT of lung lesions, often with breath-hold during CBCT.
This patient was treated with conventional fractionations.

Varian CBCT can handle "breath-hold" acquisition techniques easily.

Using CBCT to align the target and to place the target inside the high dose volume.

IMRT treatment of lung lesion with hypofractionation.

Planning of hypofractionated lung IMRT (48 Gy in 4 fractions).

Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT of a lung lesion (10 Gy X 5) treated with VMAT. These 2 plans are similar, except the hot spot (inside the PTV) for the FFF is larger than the 6X.
Second example: Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT of a lung lesion (10 Gy X 5) treated with VMAT. These 2 plans are similar, except the hot spot (inside the PTV) for the FFF is less than the 6X.

<table>
<thead>
<tr>
<th>HIM (FFF)</th>
<th>6X</th>
</tr>
</thead>
<tbody>
<tr>
<td>ips lung</td>
<td>cont lung</td>
</tr>
<tr>
<td>2590 MU</td>
<td>4330 MU</td>
</tr>
<tr>
<td>4.3 minutes</td>
<td>5.2 minutes</td>
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</tbody>
</table>

High Intensity Mode

Conventional 6X

Third example: Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT of a lung lesion (10 Gy X 5) treated with IMRT. Again, these 2 plans are similar, except the hot spot (inside the PTV) for the FFF is higher and the hot spot volume is larger than the 6X. The MUs for both plans are nearly the same.

<table>
<thead>
<tr>
<th>HIM (FFF)</th>
<th>6X</th>
</tr>
</thead>
<tbody>
<tr>
<td>ips lung</td>
<td>cont lung</td>
</tr>
<tr>
<td>4101 MU</td>
<td>4330 MU</td>
</tr>
<tr>
<td>12 minutes</td>
<td>5.2 minutes</td>
</tr>
</tbody>
</table>

High Intensity Mode

Conventional 6X

Outcome of hypofractionation of early stage lung cancer

Pre-treatment CT - PET

Post-treatment at 4 mos

This is a solitary colon met case treated with gating. 48 Gy in 4 fractions

Using VMAT for brain and spinal treatment targets

Motion during treatment is continuously monitored by infra-red sensors. The sensitivity of the infra-red system is capable of 0.1 cm. If the patient moves by more than 0.2 cm, the radiation beam is halted.

SBRT treatment of para-spinal met using IMRT

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Spine treatment using VMAT, 8Gy X 1

Frontal metastasis, single fraction, treatment with VMAT (22 Gy X 1)

Brain metastasis treated with VMAT (21 Gy), single fraction

SBRT of prostate cancer?!

(Like it or not, this is actually HERE)

We use marker seeds for prostate localization. This patient’s kV images are matched to reference DRRs using implanted seed markers. No seed migration here.
"With AP-LAT images from OBI, we have noticed more evidence of marker movements (most often 1 out of 4, but rarely all 4) in prostate patient (window / level optimized to show marker seeds)

Green circles are markers positions during simulation CT and white seeds are from AP-LAT kV X-rays.

Effect of motion on the accuracy of static images

N=17 patients, 550 real-time tracks (Calypso study — from MDA, Orlando). Motion data binned by 1 minute intervals

Assuming a "baseline true" position of the prostate:

Probability static image will introduce a set-up error >3 mm:

All fractions, all patients: 11%

Individual patients (all fractions per patient): Minimum 0.5%
Maximum 36%

Probability static image will introduce a set-up error >5 mm:

All fractions, all patients: 2%

Individual patients (all fractions per patient): Minimum 0%
Maximum 11%

Because of the concern of possible prostate movements (caused by transit material and gas), short treatment time (fast deliver) of radiation doses is necessary

Hypofractionation, these factors must be considered:

- **Patient selection** (able to tolerate gating / breath-hold, immobilization, long treatment time, ...)
- **Lack of outcome data on long term follow up** (long-term control, normal tissue tolerance, late toxicity, ...)
- **Radiation protection / shielding concerns** (linear accelerator workload, personnel exposure in "any one hour")
- **Financial issues** (machine utilization / scheduling issues, 5 X A << 45 X B)
  - Many "new" or "not so real" physics / dosimetry issues (not ready for "green" physicists - training / experience is important. Invite experienced physicists / clinicians for "hand-holding")
- **Staff and equipment utilization — a scheduling nightmare** (ACR, physicists and clinicians to attend each hypofractionated treatment)
- **High reliability treatment machine is a must** (a down machine in the middle of a hypofractionated treatment is a serious concern - **no one knows what to do with that patient**)

The very important QA issue in hypofractionated XRT:

We must keep in mind that with just a few fractions, a minor "miss" of the tumor for even just ONE fraction is **DEVASTATING**:

as compared to a 30+ fraction treatment schedule in a conventional treatment, the local control, if one fraction is "off", will be...

**NONE**
(2) Physics (technique and instrument) QA:

IGRT (isocenter coincidence between kV and MV X-ray beams)
Dosimetry QA (pre-treatment IMRT / VMAT QA)
Treatment machine QA (routine checks)
Treatment record QA (chart checks)

Because most of us know this aspect of QA quite well, I will keep this discussion short (and sweet – hopefully). And, lunch is being served!

This blended picture shows a 0.14 cm “disagreement” between the MV isocenter and kV isocenter along the superior-inferior direction. Because it is over 0.10 cm, we consider that this is NOT acceptable.

How about checking the delivered dose with a detector? We need to be careful about the types of detectors (diodes, ion-chambers) to be used in IMRT or VMAT QA measurements.

(2) Is the QA equipment suitable for this task (does it have the required spatial resolution)?

Here, the QA plan shows a dose distribution of a 2 cm wide FWHM (the “flat” portion of profile is less than 1.5 cm)

(3) Is the detector size too large?

To avoid problems with spatial resolution and detector size issues, our SBRT / VMAT QAs are done with PinPoint ionization chamber.

And, for SBRT / VMAT QA, we use GafChromatic film
Typical results of RapidArc QA with GafChromic film system

(4) How is alignment done between measured and computed data? We use MLC to radiate these alignment marks.

During the initial commissioning (for SRS or SBRT) process, were the output factors checked using field sizes set by MLCs (because one does not treat SRS or SBRT patients with X-Y collimator jaws)?

(5) Has the TPS output been validate for this type of treatments?

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Now, let’s look at the machine side of the equation for new features:

Flattening Filter Free (FFF) X-ray beams:
(1) Beam parameter definitions
(2) Ion-recombination (P-ion) issues
(3) Surface doses
(4) Small field applications
(5) Radiation protection / room shielding designs

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Long term beam stability (delivered dose)

Note: This commercially available Daily QA device works well with these FFF beams

(7) Is this QA device suitable for the HIGH Dose rate mode deliveries?

Comparisons of 6X / 6X FFF surface dose measurements

(8) Does surface doses from FFF beams need to be measured on EACH machine?
Raw data courtesy of Jie Shi, Ph.D., Sun Nuclear Corp.

(9): Beware of the very important influence of penumbra in SRS or SBRT treatments, does TPS beam model using X-Y symmetry fit this FFF data?

Profile scans of 6X FFF, 1.0X1.0 cm field (scanned with Edge detector from Sun Nuclear)

(10): With regard to radiation protection concerns:
- Has the neutron issue for the 10X FFF beam been adequately investigated?
- What is the "use factor" for FFF beams when computing radiation protection requirements?
- For municipalities which require radiation protection calculations done with instantaneous dose rates (mR/hour instead of mR in any one hour), how does one compute the barrier thickness for FFF beams?

As shown in this presentation, there is an enormous amount of work to be done by practicing clinical medical physicists. (He/she must be very good).

The convergence of imaging and treatment modalities and the ever increasing complex equipment place a severe learning burden on clinical physicists.

The duties of a clinical physicist have now become more CLINICAL than ever before.

There is a critical shortage of good clinical medical physicists in the US.

Finally, may I make a political statement, here?
AAPM is in trouble – it is not capable of addressing the man-(women-)power requirements of medical physics arena.

In fact, the American Board of Radiology (ABR) has now placed very stringent requirements for incoming practicing medical physicists. With a large number of retiring physicists in the next few years, it is creating a HUGE man-power shortage in the field.

There is no QA of manpower planning, in the US.

I sincerely hope that it is not the case in the Rest of the World (maybe, the senior physicists live much longer in ROW ???).