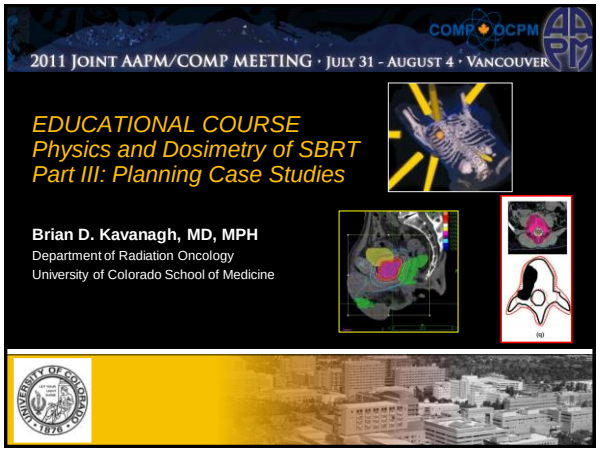



## Spectrum of applications of SBRT

- Intensified treatment to a primary cancer
  - Stage I lung cancer
  - Primary HCC
  - Pancreas cancer
  - Prostate cancer
- Palliation/control for challenging sites of recurrence
  - Spinal
  - Retroperitoneal
  - Previously irradiated volumes
- Adjuvant systemic cytoreductive therapy
  - "Radical" treatment for isolated liver, lung, spine, and other oligometastases

## SBRT Planning Case Studies

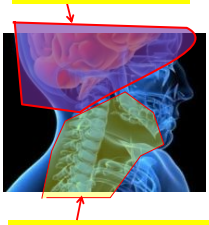
- iTreat™
  - Customized educational software app
  - Case-based instruction
    - lung-focused with connection to other sites where appropriate to other sites
- Public Service Announcement
- *Plus some questions along the way…*

COMP OCPM
2011 JOINT AAPM/COMP MEETING · JULY 31 - AUGUST 4 · VANCOUVER

## CPT code semantics

- SBRT term can be used for fractionated brain tumor SRS for the MD pro fee
  - But the delivery code is SRS
- SRS is the term used for primary OR BOOST treatment to base of skull region tumors
- SBRT describes <u>an entire course of treatment</u>, not a boost phase of treatment

Delivery code = SRS
MD pro fee = SRS if 1 fxn, SBRT for 2-5 fractions
Can be boost



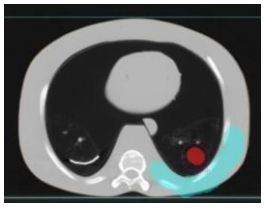
Delivery code = SBRT
MD pro fee = SBRT if 1-5 fxns
Complete course, not boost

# i.T.r.e.a.t.™

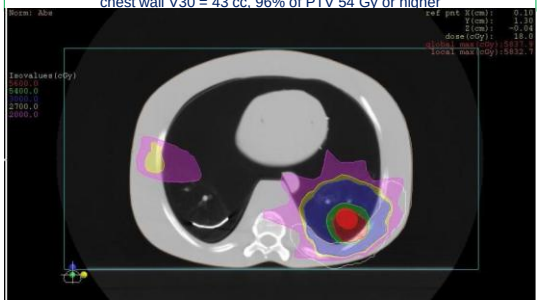
inverse Teaching, real examples, amalgamated tutorial

# The amalgamated case

- 70 y/o former opera house worker
  - heavy smoker, medically inoperable
  - his girlfriend is frightened of him
  - a bit of a stiff overall
- T1N0M0 NSCLC



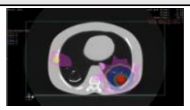
5 field IMRT
Green = 54 Gy, blue = 30 Gy, yellow = 27 Gy, magenta = 20 Gy, max = 58 Gy
PTV =ITV+5mm = 18.4 cc, V27 = 140 cc
chest wall V30 = 43 cc, 96% of PTV 54 Gy or higher



**Challenge question: what are the potential problems with this plan?**

# Possible problems

| Item | ??? | comment |
|---|---|---|
| PTV = ITV + 5mm | | |
| Dose = 54 Gy/3 | | |
| 5 field IMRT | | |
| 96% PTV > 54 Gy | | |
| Monte Carlo calculation | | |
| Dmax = 58 Gy | | |
| V27 = 140 cc | | |
| Heart max 20 Gy | | |
| Spinal cord max 17 Gy | | |
| Chest wall V30 = 43cc | | |
| Anything else? | | |



## Breathing motion management for planning & delivery

- Forced shallow breathing techniques
  - Abdominal compression
- Breath-Hold (BH) CT-Scans
  - Can be device-assisted
- Free Breathing CT-Scan
  - Slow: creates ITV
  - Fast: obtain end-inspiration & end-expiration
- Respiratory Gated CT and 4D-CTs
  - popular
- Modeled breathing motion (tracking)
  - Specific commercial system

## Quantitative analysis of abdominal pressure relative to breathing motion

*Heinzerling et al, IJROBP 70(5):1571–1578, 2008*

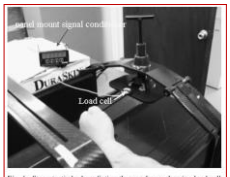



Fig. 1. Stereotactic body radiation therapy frame showing load cell and panel mount signal conditioner.

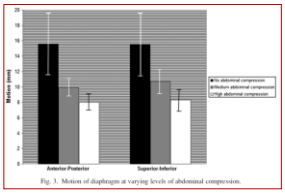


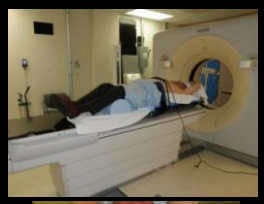

Fig. 3. Motion of diaphragm at varying levels of abdominal compression.

**Note: high compression force approx 90N, or approx 22 pounds, reduced diaphragm sup-inf motion from approx 15mm to 8 mm on average**

## Lung v liver SBRT: 2 issues

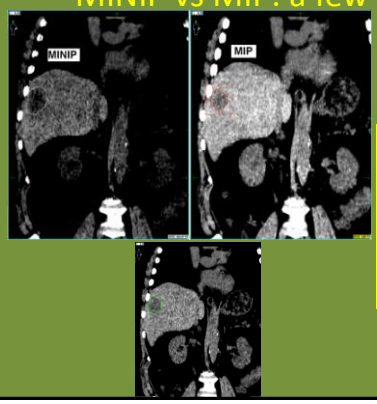
- Pressure belt placement
- MIP v MinIP to generate ITV

4D CT simulation *note: belt higher than for liver, where we don't want to deform the target organ*



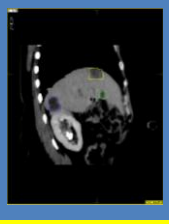
Liver case

## MINIP vs MIP: a few comments




Notice one obvious difference between MINIP and MIP is the volume of liver projected, since the lower density adjacent tissues that move with respiration provide the minimum HU voxels.

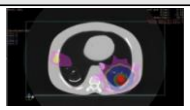
MIP usually appropriate for lung ITV
MINIP often helpful for liver ITV, but be careful with lesion near the dome



MINIP (above) helpful to show ITV for 2 of the three lesions, but 4D CT cine view (right) shows actual motion of dome lesion outside of MINIP-based ITV.

## Possible problems

| Item | ??? | comment |
|---|---|---|
| PTV = ITV + 5mm | ☺ | 4D scan or slow scan or insp/expiration |
| Dose = 54 Gy/3 | ☺ | Recalculated RTOG 0236 dose |
| 5 field IMRT | | |
| 96% PTV > 54 Gy | | |
| Monte Carlo calculation | | |
| Dmax = 58 Gy | | |
| V27 = 140 cc | | |
| Heart max 20 Gy | | |
| Spinal cord max 17 Gy | | |
| Chest wall V30 = 43cc | | |
| Anything else? | | |



According to Heinzerling et al, the application of approximately 90 N (22 pounds) of abdominal compression force reduces the average total breathing-related motion of liver or lower lobe lung tumors (rounded to nearest mm) from 14 mm to

| | |
|---|---|
| 2% | 1. 12mm |
| 90% | 2. 7mm |
| 6% | 3. 3mm |
| 1% | 4. 1mm |

According to Heinzerling et al, the application of approximately 90 N (22 pounds) of abdominal compression force reduces the average total breathing-related motion of liver or lower lobe lung tumors (rounded to nearest mm) from 14 mm to

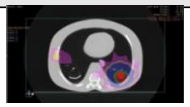
1. 12mm
2. 7mm
3. 3mm
4. 1mm

**Ref**: Heinzerling J, et al. Four-Dimensional Computed Tomography Scan Analysis of Tumor and Organ Motion at Varying Levels of Abdominal Compression During Stereotactic Treatment of Lung and Liver. Int J Rad Oncol Biol Phys 2008; 70(5): 1571-1578

**THE POINT: YOU CAN GET SUP-INF MOTION TO LESS THAN 1 CM IN MOST BUT NOT ALL CASES< AND THERE WILL ALWAYS BE SOME RESIDUAL**

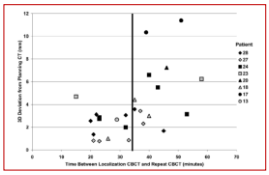
## Possible problems

| Item | ??? | comment |
|---|---|---|
| PTV = ITV + 5mm | ☺ | 4D scan or slow scan or insp/expiration |
| Dose = 54 Gy/3 | ☺ | Recalculated RTOG 0236 dose |
| 5 field IMRT | 😐 | Beware lengthy delivery, etc |
| 96% PTV > 54 Gy | | |
| Monte Carlo calculation | | |
| Dmax = 58 Gy | | |
| V27 = 140 cc | | |
| Heart max 20 Gy | | |
| Spinal cord max 17 Gy | | |
| Chest wall V30 = 43cc | | |
| Anything else? | | |

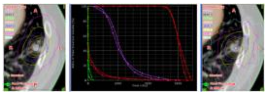


## Be mindful of intrafraction motion

Purdie et al, IJROBP 2007
Intrafraction motion, lung sbrt



Verbakel et al, Radiother Oncol 2009
VMAT for rapid delivery of SBRT

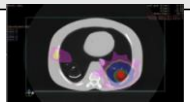


N = 3
Good dosimetry
Beam on time reduced approximately 50% using VMAT delivery

Note: rotational IMRT delivery can be faster, but another caveat applies (to be discussed later)

## Possible problems

| Item | ??? | comment |
|---|---|---|
| PTV = ITV + 5mm | ☺ | 4D scan or slow scan or insp/expiration |
| Dose = 54 Gy/3 | ☺ | Recalculated RTOG 0236 dose |
| 5 field IMRT | 😐 | Beware lengthy delivery, etc |
| 96% PTV > 54 Gy | ☺ | Good |
| Monte Carlo calculation | ☺ | Superposition/convolution , AAA also ok |
| Dmax = 58 Gy | ☹ | **Doesn't allow steep dose gradient** |
| V27 = 140 cc | | **Too much lung, R50 approximately 8** |
| Heart max 20 Gy | | |
| Spinal cord max 17 Gy | | |
| Chest wall V30 = 43cc | | |
| Anything else? | | |



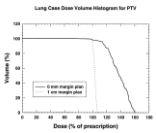
PHYSICS CONTRIBUTION

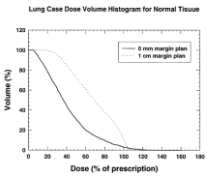
DETERMINING THE OPTIMAL BLOCK MARGIN ON THE PLANNING TARGET VOLUME FOR EXTRACRANIAL STEREOTACTIC RADIOTHERAPY

Robert M. Cardinale, M.D., Qiuwen Wu, Ph.D., Stanley H. Benedict, Ph.D., Brian D. Kavanagh, M.D., Edward Bump, B.A., and Radhe Mohan, Ph.D.

IJROBP 1999

7 non-coplanar beams
PTV DVH, 0mm v 1cm margin




**Steeper dose falloff in lung**

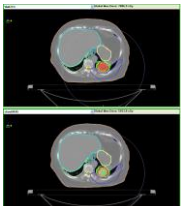
**Hotter hotspot in tumor with 0mm BEV margin v larger margin**

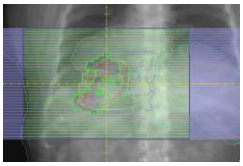
**Lower NTCP**

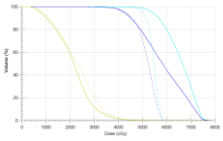
| Margin (mm) | Lung case NTCP (%) |
|---|---|
| 10 | 46 |
| 5 | 13 |
| 2.5 | 9 |
| 0.0 | 5 |
| −2.5 | 6 |

*Note: consider the NTCP estimates proof of principle, not absolute values*

## Trickier but possible:
## Hotspot creation with VMAT to steepen dose falloff gradient





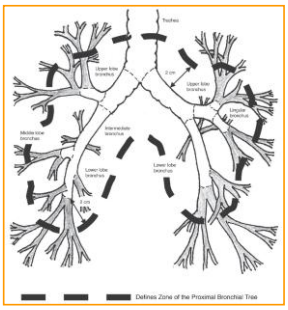


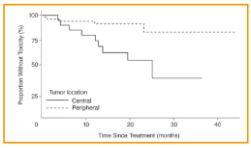
1. **VMAT delivery, total beam time 12 mins**
2. **With hotspot (above left), there is steeper dose falloff and thus lower chest wall V30 (from approx 45 to approx 35 cc)**
3. **Note: special adjustment to biological prescription parameter input needed in this system to create desirable hotspot**

## Other lung SBRT planning issues

- Anatomic location
- Chest wall dose
- Ipsilateral mean lung dose

## Cautionary note:
## *Possible* problems near the proximal airways
## **RTOG dose escalation study underway**



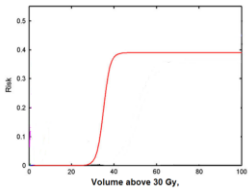




Freedom from grade 3-5 toxicity

Timmerman et al, JCO, October, 2006

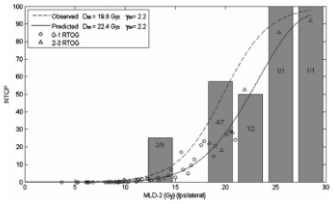
## Chest Wall Pain and/or Rib Fracture

- Dunlap et al, IJROBP 2009
  - 60 peripheral lung lesions treated with SBRT
  - 17 CWP, 5 fractures at a median of 7 months
  - Correlated to volume receiving ≥30 Gy (V30)
    - Steep increase for V30>30cc




## Radiation Pneumonitis

Ricardi et al, Acat Oncol 2009




Nearly all patients treated with 3x15 Gy regimen

- 63 patients
  - 9/63 Grade 2+ RP
- Correlated with ipsilateral Mean Lung Dose
  - corrected to 2Gy equivalent—approx same as absolute for MLD 8-10 Gy
  - **No toxicity for MLD≤ 12 Gy**

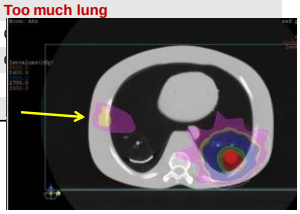
## Yamashita et al, Radiation Oncology, 2007

- 25 lung patients
  - 18 primary, 7 metastatic
- SBRT dose:
  - 48 Gy/4 fractions
  - Prescribed to isocenter
- **7/28 Grade 2 or higher RP including 3 Grade 5 toxicity**
- Essential problem:
  - Conformity Index (CI)
    - Defined as PTVmin dose volume/PTV
  - Correlated with RP (p=0.04)
  - Mean CI approx 2
    - **Very high!!!**

- *"We set the leaves at 5 mm outside the PTV…to make the dose distribution within the PTV more homogeneous. This may be the reason why we got so unacceptably high CI. We might have had to set the leaves at the margin of the PTV .... There must be something wrong with…the way targets are irradiated."*

## Possible problems

| Item | ??? | comment |
|---|---|---|
| PTV = ITV + 5mm | ☺ | 4D scan or slow scan or insp/expiration |
| Dose = 54 Gy/3 | ☺ | Recalculated RTOG 0236 dose |
| 5 field IMRT | 😐 | Beware lengthy delivery, etc |
| 96% PTV > 54 Gy | ☺ | Good |
| Monte Carlo calculation | ☺ | Superposition/convolution also ok |
| Dmax = 58 Gy | ☹ | **Doesn't allow steep dose gradient** |
| V27 = 140 cc | | **Too much lung** |
| Heart max 20 Gy | ☺ | |
| Spinal cord max 17 Gy | ☺ | |
| Chest wall V30 = 43cc | 😐 | |
| Anything else? | ☹ | |



*From U Colorado Phase II liver SBRT trial*

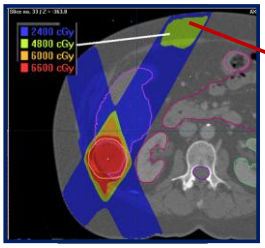
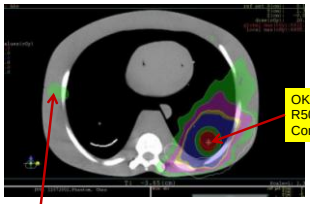




Photo taken 8 mos after SBRT
At last followup 17 post-SBRT, lesion was controlled.
Necrosis was slowly healing.

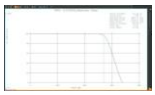
**Suggestion: no discontinous hotspot that you wouldn't want to go to spinal cord, ie 18 Gy/3fxns**

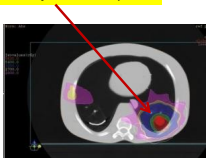
## 7 beam, non-IMRT, 0mm margin quick first pass plan already better



OK 60 Gy hotspot, could be better
R50 approx 4
Compare 56 Gy lukewarm spot

Small 15 Gy volume
No discontinuous 18 Gy





For a 3 fraction lung SBRT regimen, the following normal tissue DVH metric has been associated with increased risk of pneumonitis:

67% 1. Mean ipsilateral lung dose > 12 Gy
15% 2. Total Lung V20 > 25%
6% 3. Total Lung V15 > 35%
4% 4. Total Lung V5 > 50
8% 5. Maximum proximal bronchial tree dose > 40 Gy

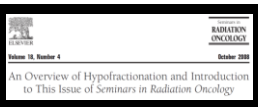
For a 3 fraction lung SBRT regimen, the following normal tissue DVH metric has been associated with increased risk of pneumonitis:

1. **Mean ipsilateral lung dose > 12 Gy**
2. Total Lung V20 > 25%
3. Total Lung V15 > 35%
4. Total Lung V5 > 50
5. Maximum proximal bronchial tree dose > 40 Gy

**Ref:** Ricardi U, et al. Dosimetric predictors of radiation-induced lung injury in stereotactic body radiation therapy. Acta Oncol 2009; 48 (4): 571-577

## Reasonable sources of guidance for SBRT normal tissue dose constraints

- Selected RTOG SBRT studies
- QUANTEC papers—very limited SBRT, mostly conventional
  - Liver
    - Pan et al, IJROBP 76(3) Suppl: S94–S100, 2010
  - Kidney
    - Dawson et al, IJROBP 76(3) Suppl: S94–S100, 2010
  - Stomach and small bowel
    - Kavanagh et al, IJROBP 76(3) Suppl: S94–S100, 2010
- Timmerman RD. Sem Rad Onc 18(4): 215-222, 2008
  - Mostly unvalidated but well considered estimates for 1, 3, and 5 fractions




Timmerman RD. Sem Rad Onc 18(4): 215-222, 2008

3 fraction dose guidelines

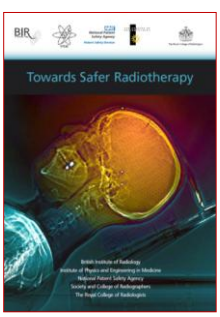
| Serial Tissue | Volume (mL) | Volume Max (Gy) | Max Point Dose (Gy) | Endpoint (≥Grade 3) |
|---|---|---|---|---|
| THREE-FRACTION TREATMENT | | | | |
| Optic pathway | <0.2 | 15 (5 Gy/fx) | 19.5 (6.5 Gy/fx) | Neuritis |
| Cochlea | | | 20 (6.67 Gy/fx) | Hearing loss |
| Brainstem | <1 | 18 (6 Gy/fx) | 23 (7.67 Gy/fx) | Cranial neuropathy |
| Spinal cord | <0.25 | 18 (6 Gy/fx) | 22 (7.33 Gy/fx) | Myelitis |
| | <1.2 | 11.1 (3.7 Gy/fx) | | |
| Cauda equina | <5 | 21.9 (7.3 Gy/fx) | 24 (8 Gy/fx) | Neuritis |
| Sacral plexus | <3 | 22.5 (7.5 Gy/fx) | 24 (8 Gy/fx) | Neuropathy |
| Esophagus* | <5 | 21 (7 Gy/fx) | 27 (9 Gy/fx) | Stenosis/fistula |
| Ipsilateral brachial plexus | <3 | 22.5 (7.5 Gy/fx) | 24 (8 Gy/fx) | Neuropathy |
| Heart/pericardium | <15 | 24 (8 Gy/fx) | 30 (10 Gy/fx) | Pericarditis |
| Great vessels | <10 | 39 (13 Gy/fx) | 45 (15 Gy/fx) | Aneurysm |
| Trachea and ipsilateral bronchus* | <4 | 15 (5 Gy/fx) | 30 (10 Gy/fx) | Stenosis/fistula |
| Skin | <10 | 22.5 (7.5 Gy/fx) | 24 (8 Gy/fx) | Ulceration |
| Stomach | <10 | 21 (7 Gy/fx) | 24 (8 Gy/fx) | Ulceration/fistula |
| Duodenum* | <5 | 15 (5 Gy/fx) | 24 (8 Gy/fx) | Ulceration |
| Jejunum/ileum* | <5 | 16.2 (5.4 Gy/fx) | 27 (9 Gy/fx) | Enteritis/obstruction |
| Colon* | <20 | 20.4 (6.8 Gy/fx) | 30 (10 Gy/fx) | Colitis/fistula |
| Rectum* | <20 | 20.4 (6.8 Gy/fx) | 30 (10 Gy/fx) | Proctitis/fistula |
| Bladder wall | <15 | 15 (5 Gy/fx) | 30 (10 Gy/fx) | Cystitis/fistula |
| Penile bulb | <3 | 21.9 (7.3 Gy/fx) | 42 (14 Gy/fx) | Impotence |
| Femoral heads (right and left) | <10 | 21.9 (7.3 Gy/fx) | | Necrosis |
| Renal hilum/vascular trunk | <2/3 volume | 18.6 (6.2 Gy/fx) | | Malignant hypertension |

| Parallel Tissue | Critical Volume (mL) | Critical Volume Dose Max (Gy) | Endpoint (≥Grade 3) |
|---|---|---|---|
| Lung (right and left) | 1,500 | 10.5 (3.5 Gy/fx) | Basic lung function |
| Lung (right and left) | 1,000 | 11.4 (3.8 Gy/fx) | Pneumonitis |
| Liver | 700 | 17.1 (5.7 Gy/fx) | Basic liver function |
| Renal cortex (right and left) | 200 | 14.4 (4.8 Gy/fx) | Basic renal function |

## Public Service Announcement

- Safety and quality in the performance of high-tech radiation therapy services is of the highest priority
- ASTRO has been creating a series of "White Papers" and other documents laying out details
  - Eg, SBRT White Paper
    - Special thanks: Tim Solberg


## "Towards Safer Radiotherapy"

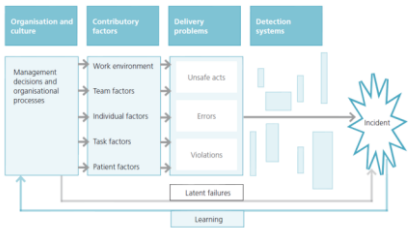



- Published 4/2008
- Contains analysis of UK data
- Estimate a rate of 3/100,000 risk of a course of treatment involving ≥10Gy overdose

https://www.rcr.ac.uk/docs/oncology/pdf/Towards_saferRT_final.pdf

## “Towards Safer Radiotherapy”, continued

Figure 2.1 Reason’s model of organisational accident




https://www.rcr.ac.uk/docs/oncology/pdf/Towards_saferRT_final.pdf

## “Towards Safer Radiotherapy”, continued

- Error definition/grading scale provided
- Checklists encouraged
- For the UK a national reporting system established

https://www.rcr.ac.uk/docs/oncology/pdf/Towards_saferRT_final.pdf

## Ongoing data reporting/analysis


**Most “near misses” occur at the treatment unit**

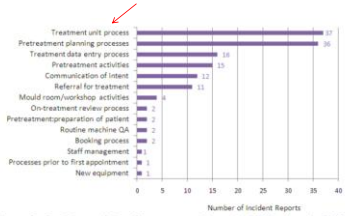



*Figure 5. Breakdown of Near Misses extracted from the NRLS using the TSRT9 trigger code. August 2010 to October 2010 (n=142).*

http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1296683183960

## Additional sources of guidelines for SBRT performance

- Potters L, et al. American Society for Therapeutic Radiology and Oncology (ASTRO) and American College of Radiology (ACR) practice guideline for the performance of stereotactic body radiation therapy. Int J Radiat Oncol Biol Phys. 2010 Feb 1;76(2):326-32.
- Benedict SH, et al. Stereotactic Body Radiation Therapy: The Report of AAPM Task Group 101. Med Phys. 2010 Aug; 37(8):4078-101

Data recorded from the UK's "Towards Safer Radiotherapy" project indicates that the most common source of radiation treatment error "near misses" is the following:

| | |
|---|---|
| 5% | 1. Scheduled linac QA checks |
| 11% | 2. Inaccurate patient-specific QA verification |
| 2% | 3. Planning software programming errors |
| 2% | 4. New equipment commissioning |
| 81% | 5. Procedures at the point of RT delivery |

Data recorded from the UK's "Towards Safer Radiotherapy" project indicates that the most common source of radiation treatment error "near misses" is the following:

1. Scheduled linac QA checks
2. Inaccurate patient-specific QA verification
3. Planning software programming errors
4. New equipment commissioning
5. **Procedures at the point of RT delivery**

**Ref:**"Towards Safer Radiotherapy"
www.rcr.ac.uk/docs/oncology/pdf/Towards_saferRT_final.pdf
Also cf. SAFER RADIOTHERAPY, The Radiotherapy Newsletter of the HPA. Supplementary Data Analysis; ISSUE 3 - Full Quarterly Radiotherapy Error Data Analysis: August 2010 to October 2010,
www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1296683183960