A 2D beam-quality specifier for photon beams with and without flattning filter

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Purpose

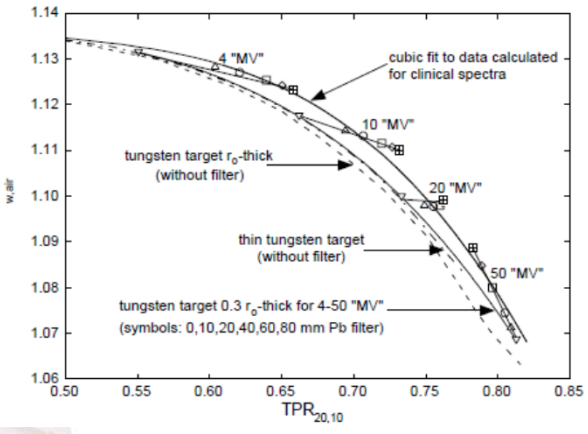
To evaluate a beam-quality specifier
with two components
for non-standard, high-energy photon beams

Background

- Treatments with FFF-beams have become routine
  – TomoTherapy , CyberKnife ,Varian TrueBeam, Elekta Versa HD
- Uncertainty in reference dosimetry[1]
  - Dose to water in reference situation: 1.5 %
  - Assignment of $S_{w,air}$ to beam quality:0.2 %
- Is the same level of uncertainty achievable for non-standard flattening filter-free beams ?

[1]Andreo *et al.*, *IAEA*, TRS-398 (2000)

Background



[1]Andreo *et al.*, *IAEA*, TRS-398 (2000)

Previous investigation[1]

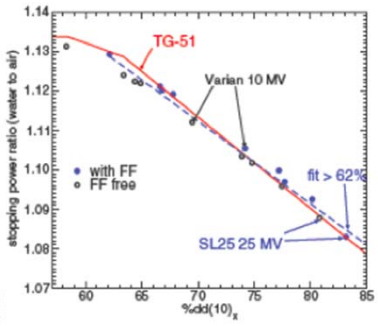


FIG. 1. Values of $\%dd(10)_x$ and Spencer–Attix mass restricted collision water to air stopping power ratios, $(\bar{L}/\rho)^{water}_{air}$, calculated using full accelerator simulations for cases with (WFF) or without (FFF) flattening filters. The solid line shows the values used in the AAPM's TG-51 protocol (Ref. 1) and the dashed line shows a best fit to all the present data with $\%dd(10)_x > 62\%$.

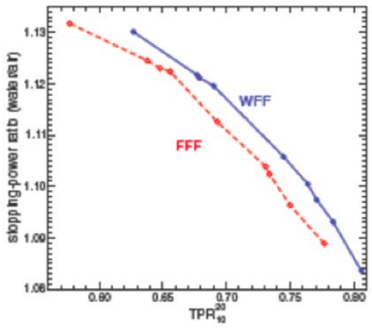


FIG. 7. Relationship between TPR^{20}_{10} and the Spencer–Attix restricted stopping-power ratio for both the WFF and FFF beams.

[1]Xiong and Rogers, *Med. Phys.* **35**:2104 (2008)

Previous investigation[2]

- 2D-fit derived from the Kerma-weighted μ–distribution
  - Average linear attenuation coefficient
  - Coefficient of variation

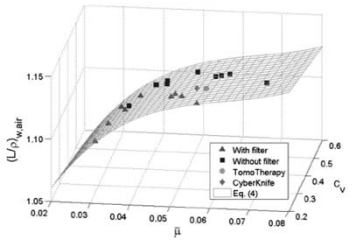
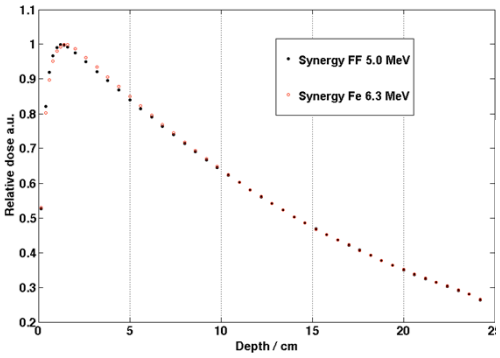


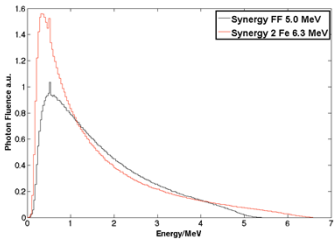
FIG. 2. Monte Carlo calculated $(\bar{L}/\rho)^{water}_{air}$ values (from Ref. 13, Table I) as a function of spectral mean ($\bar{\mu}$) and coefficient of variation (c_v) for the nine different beams, with and without flattening filter, used in this work. The gridded surface represents the fitted Eq. (4). Please note that this 3D representation is for illustration only, and that the gridded surface has been extended outside the fitting domain for better visualization.

[2]Ceberg et al., *Med. Phys.* **35**:1164 (2010)

Depth dose comparison



	$Tpr_{20/10}$	$Tpr_{10/5}$	$SPR_{w,air}$
FF	0.6571	0.8386	1.1229
FFF	0.6564	0.8308	1.1206
Δ	0.1 %	0.9 %	0.2 %



Material and methods

- EGSnrc (BEAMncr, SPRRnrc, DOSRnrc)
- Full simulation
  - Elekta Synergy FF and FFF
- IAEA- phsp
  - Varian TrueBeam 6 MV and 10 MV FF and FFF
  - Elekta Precise 6 MV and 10 MV FF
  - CyberKnife

https://www-nds.iaea.org/phsp

Material and methods - Beams used

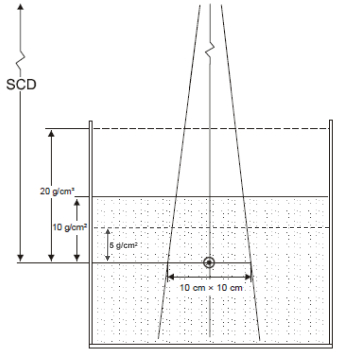
Elekta Synergy			Elekta Precise	Varian TrueBeam		CyberKnife
FF	FFF 2 mm Fe	FFF 6mm Cu	FF	FF	FFF	FFF
5.0 (a)	6.3 (g)	6.3* (q)	5.75 (g)	6.18 (i)	5.9 (w)	7.0† (y)
5.7 (b)	7.0 (h)	7.0 (r)	9.4 (h)	10.7 (j)	10.2 (x)	
6.3* (c)	7.9 (m)	7.9 (s)				
6.6 (d)	8.5 (n)	8.5 (t)				
7.6 (e)	9.2 (o)	9.2 (u)				
8.1 (f)	10.0 (p)	10.0 (v)				

* Mean incident electron energy that produce a photon beam matching measurements at the departments of medical physics, Skåne University Hospital, Lund, Sweden.
† The incident electron beam in the CyberKnife model is monoenergetic.

from Xiong and Rogers, *Med. Phys.* **35**:2104 (2008)

Material and methods

- Monte Carlo simulated data
  - $TPR_{20/10}$, $TPR_{10/5}$
  - Stopping-power ratios
- Modelling the relation $S_{w,air}(TPR_{20/10}, TPR_{10/5})$



Relation between $s_{w,air}$ and ($TPR_{20/}10$,$TPR_{10/5}$)

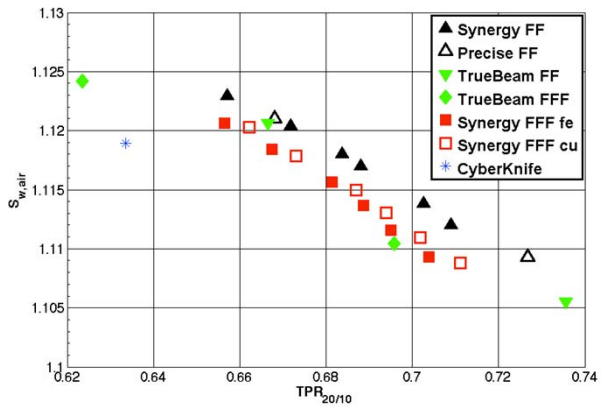
- A two-dimensional model was fit to the data

$$S_{w,air} = a_1 + a_2\left(TPR_{20/10}\right) + a_3\left(TPR_{20/10}\right)^2 + a_4\left(TPR_{20/10}\right)^3 + a_5\left(TPR_{10/5}\right)$$

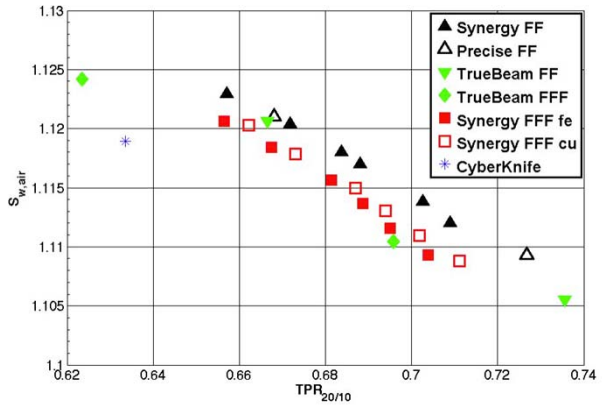
- The constants were determind by least-squares fitting

$a_1 = 0.8905$
$a_2 = 0.09614$
$a_3 = 0.7706$
$a_4 = 0.3591$
$a_5 = -0.4779$

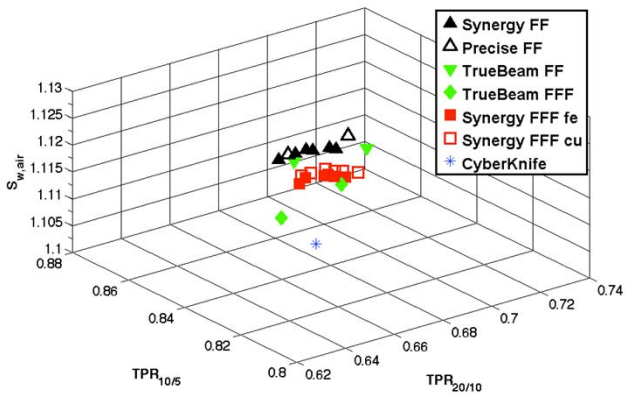
Results



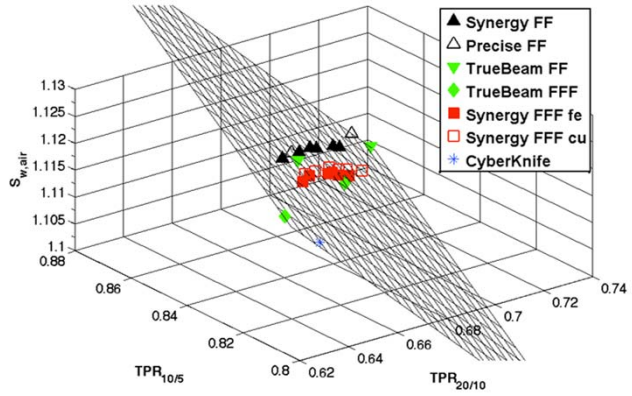
Results



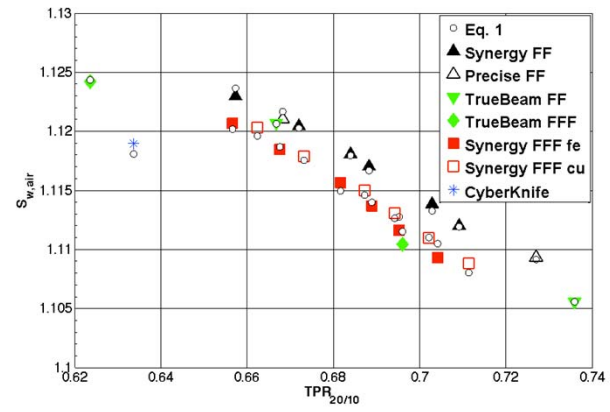
Results



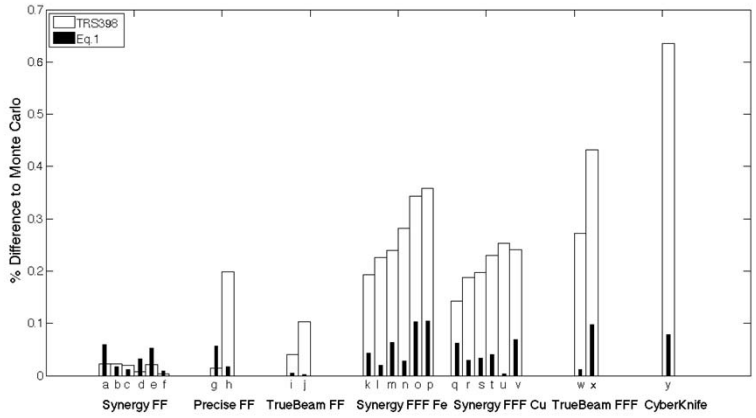
Results



Results



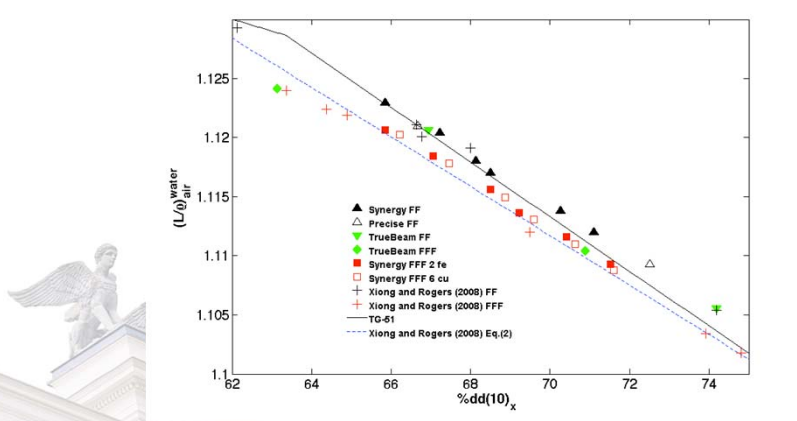
Results



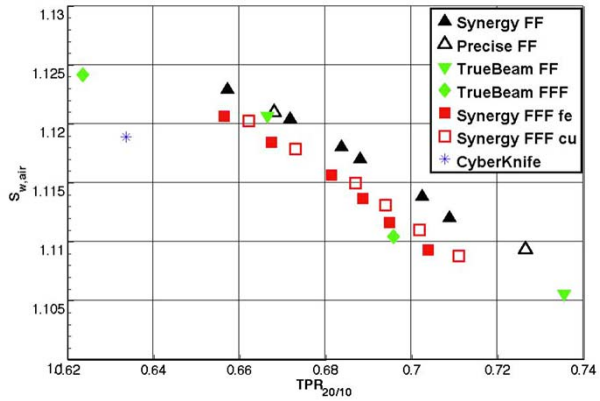
Conclusions

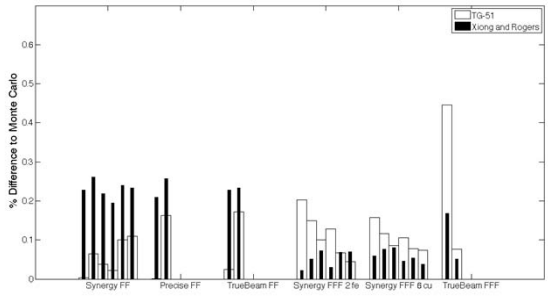
- Using $TPR_{20/10}$ in assigning $S_{w,air}$-values for flattning filter-free beams could lead to a systematic overestimation of about 0.3 %
- By adding TPR10/5 the predicion of Sw,air will be improved
- Potential for CyberKnife

Tack för uppmärksamheten



Results


Synergy FF
Precise FF
TrueBeam FF
TrueBeam FFF
Synergy FFF fe
Synergy FFF cu
CyberKnife
1.13
1.125
1.12
1.115
1.11
1.105
0.62
0.64
0.66
0.68
0.7
0.72
0.74
$S_{w,air}$
$TPR_{20/10}$


TG-51
Xiong and Rogers
% Difference to Monte Carlo
0.6
0.5
0.4
0.3
0.2
0.1
0
Synergy FF
Precise FF
TrueBeam FF
Synergy FFF 2 fe
Synergy FFF 6 cu
TrueBeam FFF

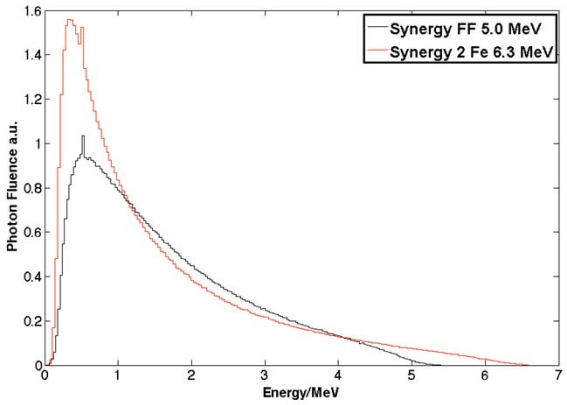
$$k_{Q,Q_0} = \frac{(S_{w,air})_Q (W_{air})_Q \, p_Q}{(S_{w,air})_{Q_0} (W_{air})_{Q_0} \, p_{Q_0}}$$

Effect on $S_{w,air}$[1]

- Change in the spectra by removing the flattening filter
  - Increase 0.3-0.7 %
- Spectral composition averaged over entire field
  - Increase 0.22 % for beams with flattening filter
- Realistic or flat fluence profiles
  - 0.01-0.06 % for FFF beams
- Variation on central axis has largest influence

[1]Xiong and Rogers, *Med. Phys.* **35**:2104 (2008)

Spectral comparison



Previous investigation[1]

- Ability of common beam quality specifiers to predict $s_{w,air}$ in flattening-filter free linac beams
- Using $\%dd(10)_x$ according to TG-51:
  - RMSD=0.30%
  - Flattening-filter free 4-6 MV beams are problematic
- Using $TPR_{20,10}$ according to TRS-398:
  - Deviations of up to 0.4-1.0%

[1]Xiong and Rogers, *Med. Phys.* **35**:2104 (2008)