VALIDATION OF PROTON STOPPING POWER RATIOS FOR TISSUE SURROGATES IN AN ELECTRON DENSITY PHANTOM

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Objective
For tissue surrogate inserts of an electron density phantom compare measured proton stopping power ratios to water (SPR's) to calculated SPR's based on mass density, electron density and elemental composition provided by the phantom manufacturer.

Conclusions
Using measured mass densities, the agreement between calculated and measured SPRs were within 1.3 %. The mass densities of the two lung tissue surrogate inserts provided by the manufacturer were not reliable.

Background

A calibration curve relating the Hounsfield Units (HU) from computed tomography (CT) images to SPR's for protons is necessary information for the proton treatment planning system Eclipse® (Varian Medical Systems). For the CT scanner used at Sahlgrenska University Hospital, this curve is created using the stoichiometric method described by Schneider [1]. In this process a commercial electron density phantom with different tissue surrogates is scanned in the CT scanner and SPR's are calculated for each tissue surrogate using the mass density, the relative electron density and the elemental composition provided by the manufacturer.

Materials & Methods

Eight tissue surrogate inserts of the electron density phantom (062M, CIRS Inc.) were evaluated. The mass densities of the inserts were validated with a digital caliper (MahrCal 16ER) and a precision scale (Sartorius MC210P). Two tissue surrogate inserts (Lung inhale/exhale) had a different lid material and the lid was therefore removed before the measurements (Figure 1).

Theoretical SPR's were calculated for 226 MeV protons using expressions from Schneider [1], the measured density of the inserts, and mean excitation energies from ICRU 37 [2].

The SPR for each insert was determined with a residual range measurement of a 226 MeV single spot proton beam, using the cyclotron (Proteus PLUS, IBA) at the Skandionkliniken. Integrated Depth Ionization Curves (IDIC's) were measured with an ionization chamber (Bragg peak 34070, PTW) behind each insert (Figure 2).

The measurement setup was validated with five additional well-known materials, measured as described above and compared to calculated [1,2] and tabulated data [3].

A cubic spline function was fitted to the measured data points of the IDIC's in MATLAB (Mathworks Inc.). The resulting curves were normalized to 100% at the Bragg peak. The range of the distal 80% and 50% dose levels was extracted, and the mean value was used as the range parameter.

Figure 1. CIRS electron density phantom model 062A with eight tissue surrogate inserts. The top of the two lung tissue inserts was removed since they were made of other material. To the right five well-known materials made locally.

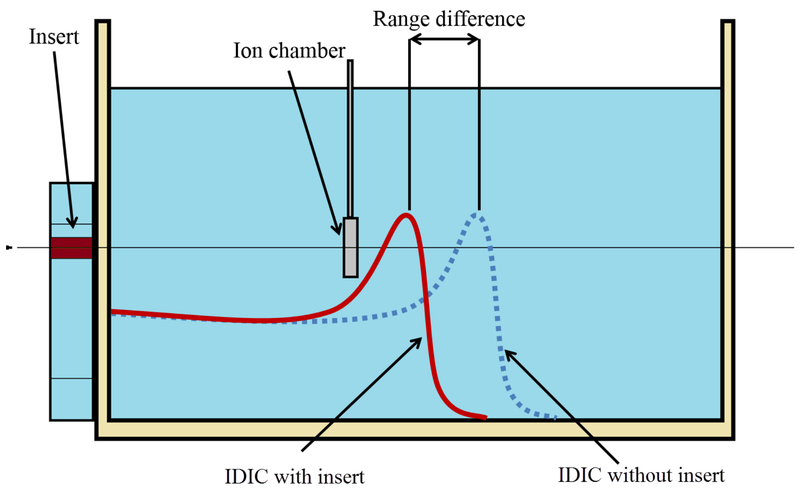

Figure 2. Setup for the measurement of residual range.
IDIC= Integrated Depth Ionization Curve.
Insert = Eight tissue surrogate inserts and 5 well-known materials

Table 1. Comparison of measured mass density and mass density provided by the manufacturer.

CIRS ® materials	Measured mass density [g/cc]	Tabulated mass density from CIRS® [g/cc]	Deviation [%]
Lung inhale	0.176	0.195	**10.8%**
Lung exhale	0.485	0.510	**5.2%**
Adipose	0.969	0.960	**-0.9%**
Breast 50/50	1.000	0.991	**-0.9%**
Muscle	1.062	1.062	**0.0%**
Trabec Bone 200	1.174	1.161	**-1.1%**
Bone 1250 HA	1.824	1.820	**-0.2%**
Bone 1750 HA	2.155	2.150	**-0.2%**

Table 2. Comparison of measured and calculated proton stopping power ratios to water (SPR).*
** Calculated using the measured mass density*

CIRS ® materials	Measured SPR	Calculated* SPR	Deviation [%]
Lung inhale	0.177	0.174	**-1.3%**
Lung exhale	0.478	0.481	**0.7%**
Adipose	0.980	0.976	**-0.4%**
Breast 50/50	1.004	1.001	**-0.3%**
Muscle	1.057	1.056	**-0.1%**
Trabec Bone 200	1.121	1.124	**0.3%**
Bone 1250 HA	1.627	1.623	**-0.3%**
Bone 1750 HA	1.868	1.862	**-0.3%**

Table 3. Measured, calculated [1,2] and tabulated [3] SPR's for well-known materials.
** Polystyrene was regarded a well-known material but an unknown amount of TiO_2 was discovered and the material was excluded.*

Well-known materials	Measured Mass density [g/cc]	Calculated SPR	Tabulated SPR	Measured SPR	Deviation to calculated SPR [%]	Deviation to tabulated SPR [%]
Polyethylene	0.932	0.992	0.989	0.993	**0.1%**	**0.5%**
PMMA	1.185	1.162	1.155	1.160	**-0.2%**	**0.4%**
Graphite	1.683	1.505	1.506	1.504	**-0.1%**	**-0.1%**
PTFE	2.161	1.803	1.810	1.802	**-0.1%**	**-0.5%**
Polystyrene*	1.038			1.030		

References

[1] Schneider U, Pedroni E and Lomax A, The calibration of CT Hounsfield units for radiotherapy treatment planning, *Phys.Med.Biol.* **41** (1996),111-124.

[2] ICRU 1989 Stopping powers for electrons and positrons *ICRU Report* 37

[3] PSTAR, National Institute of Standards and Technology (NIST), http://www.nist.gov.

Results

The mass densities of the eight tissue surrogate inserts given by the manufacturer deviated from measured mass density with up to 10.8% (Table 1).

The measured SPR's of the tissue surrogate inserts agreed within ±1.3% of calculated SPR's (Table 2).

The measured SPR's of the well-known materials agreed with calculated SPR's within 0.2% and within 0.5% to tabulated data (Table 3).

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