Simplistic Tomotherapy Model Predicts RayStation Treatment Times Within 20% for First 16 Plans

P. KING[1], C. SAWYERS[2], S. ANDERSON[1], K. GADDAM[1], C DULANEY[1], R. JORDAN[1], G. THOMPSON[1]

1Anderson Regional Medical Ctr., Meridian, MS

2RaySearch Americas, New York, NY

Purpose

Helical tomotherapy treatment times are large, variable, and non-intuitive in relation to prescribed dose. It would be useful[1] to describe a helical tomotherapy beam as equivalent to a broad, fixed, modulated beam; one more amenable to calculation by a measurement-free, pseudo-classical approach that is both simple enough to be computed by hand and intuitively sensible in-terms of classical broad-beam radiotherapy. The goal here is to propose such an approach and evaluate its promise as applied to helical tomotherapy plans developed using the RayStation TPS.

Model

$$RX = CDR * t_{tx} * Tf_{couch} * Tf_{mlc} * Tf_{jaw} * TMR_{eff}$$

The proposed model treats delivered dose as the product of output, time, TMR; and net transmission through the couch, MLC, and jaws.

Treatment time is the quanity desired, and is reported in the RaySation plan. Output dose rate is a fixed property of the accelerator.

$$CDR = \frac{861\,cGy}{60\,sec}$$

Couch attenuation is treated as a a constant of the treatment unit and was determined by calculation of the 2.5 cm RayStation output commissioning plan, with the couchtop model both present and absent.

$$Tf_{couch} = 0.983$$

Attenuation due to the MLC sinogram is taken to be the reciprocal of the RayStation-provided modulation factor.

$$Tf_{mlc} = \frac{1}{MF_{raystation}}$$

The effect of couch motion and dynamic jaw motion is treated as analogous to a dynamic wedge, whose transmission factor is the proportion of time for which the major parts of the target are exposed to the open jaws. This is determined as the ratio of open jaw size to irradiated length. Maximum jaw settings are 1, 2.5, and 5-cm. In dynamic mode, the minimum jaw setting is 1-cm. The presence of time as a factor, is as a convenience in finding the distance traveled by the couch.

$$Tf_{jaw} = \frac{JAW_{max}}{JAW_{min} + (speed_{couch} * t_{delivery})}$$

Tabulated values of tissue-maximum-ratio are not readily available for Tomotherapy. TMR values are obtained from the parameterized, published equation for TMR described by Schell[2] for 6 MV x-rays, using an approximate field size implied by the target's volume, and mean depth implied by the patient's cross-sectional area.

```
A,B,C,E,F = 0.0414, 0.0448, -0.0772, 1.111, 0.0510
def k(d):
    return scipy.interpolate.interp1d([1.5, 6, 10, 16, 20, 50], [0, 0.208, 0.170, 0.130, 0.118, 0.118])(d)
def schell_tmr(fs, d):
    fs = 0.45 * fs
    term1 = A*d*np.exp(-B*d) + C
    term2 = 1-np.exp(-k(d)*fs)
    term3 = E*np.exp(-F*d)
    return term1*term2+term3
```

Because helical beams treat from all angles, the volume and thickness of the central slice are used to approximate average depth, which is scaled by average density to produce effective depth. Because all angles are used, average density tends toward unity. RayStation reports average CT# and a simple formula is used to convert this to approximate density for densities close to one.

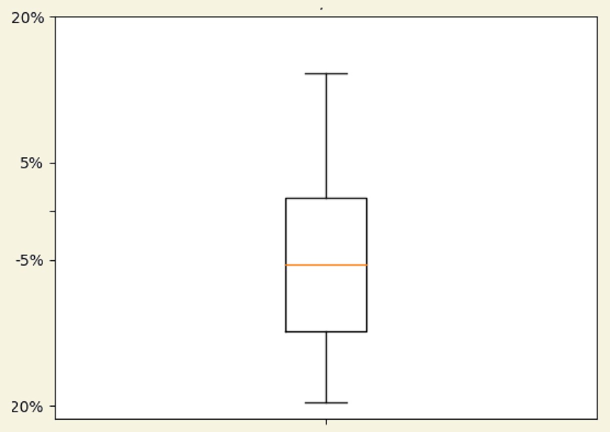
$$d_{eff} = \bar{\rho}\left(\frac{V_{slice}}{\pi\, t_{slice}}\right)^{\frac{1}{2}}$$

$$\bar{\rho} = 1 + \frac{19 * HU_{raystation}}{20{,}000}$$

Approximating the target as spherical, the average projected field size is converted to a circle, which is then converted to an equivalent square using Day's factor[3] of 0.9. Because treatment margin is neglected, this method produces a conservative, albeit consistent, estimate of equivalent square.

$$EqSq_{eff} = 1.8\left(\frac{3\,V_{target}}{4\pi}\right)^{\frac{1}{3}}$$

Result



For the initial series of 16 Tomotherapy plans (11 patients), the treatment times calculated using this model were compared to the time predicted by RayStation. In all cases, these values agreed within 20%. In 5 cases, agreement was within 5%. Modeling a volumetric, helical tomotherapy plan as an intuitively-equivalent broad-beam point dose calculation, using no measured data, is an over-simplification which radically suppresses the true complexity of helical tomotherapy. Yet, it results in significant agreement in calculated dose. Only one-third of cases showed the 5% level of agreement expected of a full and sufficient verification method. With further refinement, this might be improved. However, the level of agreement observed is sufficient to be useful, particularly as this method creates an intuitive connection to the classical methods, as well as to the clinically tangible characteristics of the plan. This approach shows promise.

References

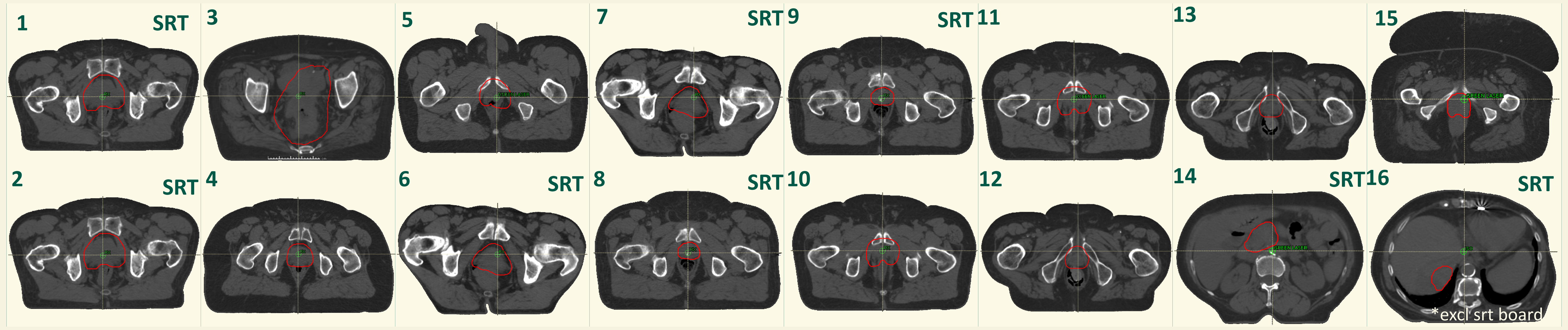
[1] J. P. Gibbons, K. Smith, D. Cheek, and I. Rosen, "Independent calculation of dose from a helical TomoTherapy unit", J Appl Clin Med Phys, 10, 103-119 (2009).

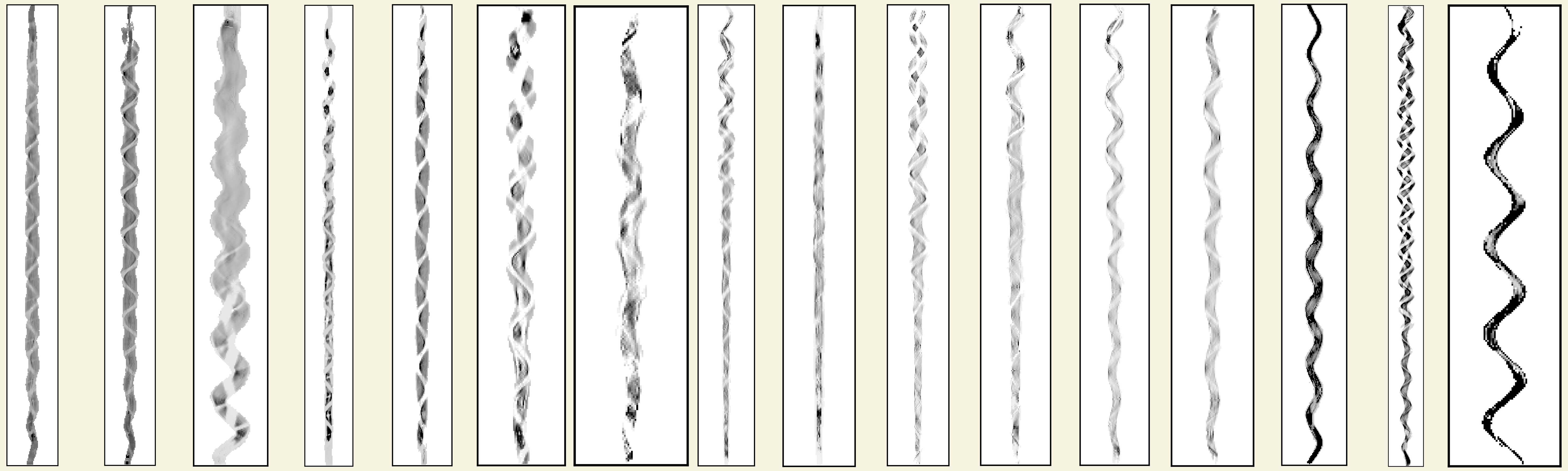
[2] M. C. Schell and J. A. Deye, "Empirical equation for tissue-maximum ratio/scatter-maximum ratios for indirectly ionizing radiotherapy beams", Med Phys, 6, 65-67 (1979).

[3] M. J. Day, "The equivalent field method for axial dose determinations in rectangular fields", British Journal of Radiology, Suppl 11, 95-100 (1972).

Plans

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Site	Prost	Prost Bst	Rectum	Prost Bst	Prost Bst	Prost	Prost Bst	Prost	Prost Bst	Pr Bed	Pr Bed Bst	Prost	Prost Bst	Pancreas	Pelvis	Liver Bst
Fx / Sub-fx	750/3	750/3	180	200	200	750/3	750/3	750/3	750/3	200	200	180	200	750/3	180	700/3
Rx to	median	median	99%ISO	median	ISO	median	median	median	median	median	median	median	median	median	median	median
Slice (cm^3)	149.90	149.90	223.13	227.94	212.39	119.33	119.33	168.71	168.71	164.92	164.92	124.21	124.21	107.57	401.69	114.48
Slice (cm)	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2
Mean HU	24.17	24.17	-18.57	-18.21	3.52	68.00	68.00	7.07	7.07	2.36	2.36	-10.01	-10.01	-2.14	-41.06	-25.7*
Target (cm^3)	201.78	165.49	811.96	141.38	104.09	67.73	41.68	75.56	50.27	202.64	114.25	79.47	59.38	70.17	422.42	16.05
Eq Sq (cm)	6.5	6.1	10.4	5.8	5.3	4.6	3.9	4.7	4.1	6.6	5.4	4.8	4.4	4.6	8.4	2.8
TMR	0.575	0.571	0.627	0.498	0.498	0.585	0.577	0.538	0.532	0.564	0.552	0.608	0.603	0.631	0.498	0.606





	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Jaws	5 dyn	5 dyn	5 dyn	5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn	2.5 dyn
MF	2.25	2.43	3.92	3.20	2.615	3.37	3.37	4.01	4.389	4.987	5.06	5.59	4.98	1.63	2.058	1.25
Pitch	0.233	0.233	0.434	0.233	0.350	0.436	0.436	0.443	0.443	0.430	0.430	0.430	0.430	0.440	0.430	0.430
Couch (cm/s)	0.074	0.069	0.063	0.052	0.036	0.019	0.019	0.020	0.019	0.018	0.018	0.019	0.019	0.059	0.048	0.056
Period (s)	15.80	17.00	35.00	19.10	24.60	58.00	58.60	56.40	57.90	59.90	60.00	55.90	58.20	18.70	22.40	19.20
Time (s)	178	191	272	230	239	381	298	576	464	563	495	466	407	166	368	99
Error (%)	-9.1%	-10.2%	-4.5%	-16.0%	-15.5%	-14.2%	+10.0%	-11.4%	-19.7%	+1.1%	-3.5%	-0.3%	+2.0%	-15.9%	-6.6%	+8.7%

Poster Number: PO-GePV-T-278
Presented at AAPM 61st Annual Meeting & Exhibition
July 14-18, 2019

1704 23rd Avenue
First Floor
Meridian, Mississippi 39301