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Planning dose constraint corrections for increasing accuracy in radiotherapy

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INTRODUCTION

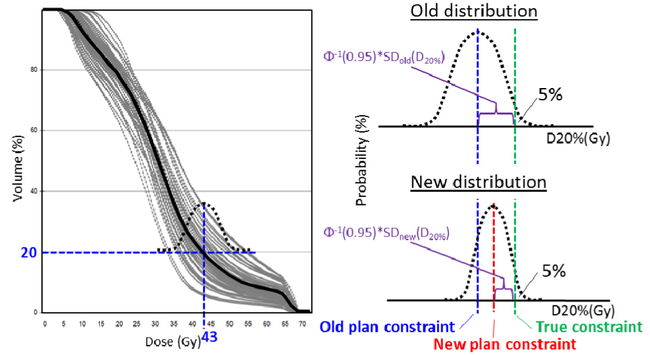
Planning dose constraints generally are derived from old dose-effect data, when treatment accuracy was less than now. Our proposition is that these constraints should not be used for modern, more accurate, treatment techniques, but that adjustments must be made.

AIM

To develop a model that corrects old dose constraints for application in new radiotherapy techniques.

METHOD

A formula for the calculation of new planning constraints can be derived as follows. **Figure, Left**: Imagine an *old* planned DVH for an OAR (black) used to determine a planning DVH constraint (blue) $D_{20\%}$=43Gy, with NTCP<5%. Now, actually delivered DVH curves are spread around the planned curve, depending on the treatment accuracy of the plan (grey). The dashed curve then shows the normal distribution of actual $D_{20\%}$ with standard deviation $SD_{D20\%,old}$. **Right, Upper**: If we assume that the worst 5% of these DVHs are responsible for the complications, we can determine the True constraint (green), i.e. the real threshold above which complications occur. The True constraint has a dose value $\phi^{-1}(1\text{-}5\%) * SD_{D20\%,old}$ higher than the planned constraint, with $\phi^{-1}(1\text{-}X\%)$ the inverse error function that gives the threshold (in SD) corresponding to the X% largest values in a normal distribution. **Right, Lower**: In a *new* situation with smaller uncertainties, using the same NTCP and True constraint gives a New plan constraint (in red) of $\phi^{-1}(1\text{-}5\%) * SD_{D20\%,new}$ Gy lower than the True dose constraint, so in general it follows that:



$$D_{crit,new} = D_{crit,old} + \phi^{-1}(1\text{-}NTCP) * (SD_{Dcrit,old} - SD_{Dcrit,new}).$$

We applied this formula to Quantec [1] dose-constraints. To get a first estimate of SD_{Dcrit} values, we simulated (Monte-Carlo, >100 runs) systematic geometric errors (Σ) up to 4mm (1SD) in current treatment plans and calculated DVHs. The spread (1SD) in various D_{crit} (D_{max}, D_{mean}, $D_{50\%}$, $D_{25\%}$, $D_{10\%}$, $D_{5\%}$, $D_{1\%}$) was calculated for relevant OARs (i.e. $D_{OAR,max} > 70\%*D_{prescribed}$). Subsequently, accuracy during acquisition of Quantec data (ca. 20yrs ago) was assumed to be Σ=4mm vs Σ=2mm nowadays.

RESULTS

Included were 71 widely varying treatment plans with 305 relevant OARs. Average variations of critical doses at Σ=2mm and Σ=4mm, are shown in **table 1**. On average critical dose variations become 2.4% higher.

Applying the **formula** with data from **table 1** on 22 Quantec planning dose constraints yields **table 2**. We found that *True* constraints are on average 2.4Gy higher, while *New* constraints are on average 1.1Gy higher.

Table 1: SD_{Dcrit} (%)

Dcrit	Σ=2mm	Σ=4mm	Δ
D_{max}	2.8	4.0	1.2
D_{mean}	2.5	4.7	2.1
$D_{1\%}$	4.0	6.5	2.5
$D_{5\%}$	4.4	7.3	3.0
$D_{10\%}$	4.4	7.6	3.2
$D_{25\%}$	3.5	6.4	2.9
$D_{50\%}$	2.3	4.5	2.2
mean	**3.4**	**5.9**	**2.4**
SD	**0.8**	**1.3**	**0.6**

Table 1*: mean variation (1SD) in critical doses for 305 OARs from MC simulations with Σ = 2 and 4 mm. Dose values (in%) are normalized to prescription dose. Δ is the difference.*

Table 2*: application of the formula to 22 Quantec dose criteria using SD_{Dcrit} data from table 1. The Old, True, and New values for various D_{max}, D_{mean}, and DVH constraints (Gy) are shown in the last three columns.*

Table 2: Old, True, New Quantec constraints

Type	Organ	Complication	NTCP (%)	Volume (%)	Dose Thresholds (Gy) Old	True	New
D_{max}	Spinal cord	Myelitis (single dose)	1		13	14.2	13.4
	Spinal cord	Myelitis	0.2		50	56	52
	Brainstem	Cranial neuropathy	5		54	58	55
	Optic pathway	Optic neuropathy	3		55	59	56
	Brain	Necrosis	3		60	65	61
	Bladder	Grade 3 tox. (bladder Tx)	6		65	69	66
	Larynx	Oedema/dysfunction	20		66	68	67
D_{mean}	Cochlea	Hearing loss	30		45	46	46
	Liver	RILD	5		30	32	31
	Lungs	Pneumonitis	5		7	7.5	7.3
	Parotid	75% function loss	20		25	26	25
	Pharynx	Dysphagia	20		50	52	51
DVH	Bladder	Grade 3 tox. (prostate Tx)	10	50	65	69	67
	Oesophagus	Esophagitis grade 2	30	40	50	51	51
	Heart	Pericarditis	15	46	30	31	31
	Heart	Long term morbidity	1	10	25	28	26
	Kidney	Dysfunction	5	30	23	25	24
	Larynx	Oedema/dysfunction	20	27	50	52	51
	Lungs	Pneumonitis	20	30	20	21	20
	Penile bulb	Impotence	35	90	50	51	50
	Rectum	Grade 2 tox.	15	25	65	68	66
	Stomach	Ulceration/fistula	7	100	45	48	46
Average					**47.4**	**49.8**	**48.4**

CONCLUSIONS

Our new formula calculates true and new dose planning constraints from existing older constraints.

It shows how, with increasing radiotherapy accuracy, higher dose constraints can be applied while maintaining the same NTCP.

After determining the critical dose variations in *measured* DVHs, the formula can also be applied to set new dose criteria for measurements.

CURRENT LIMITATIONS

Our formula has been applied with only rough estimates for uncertainties now and in the past. This will be refined in future calculations.

Furthermore, the critical dose variations have been averaged over all organs at risk. This will be separated so that for each constraint, the appropriate new constraints can be calculated more accurately.

REFERENCES

[1] Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 3, Supplement, pp. S10–S19, 2010

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