Characteristics of the Minimum Absorbed Doses for Small Lesions as Derived from Simulations

The minimum absorbed dose (AD) uses a fixed sphere volume of interest (VOI) that equals the size of the lower limit of determinability of the applied volume segmentation method. Thus, this fixed volume is larger than or equal to the actual lesion size; those lesions are termed small lesions. In the following, the fixed and actual volumes and the respective diameters are denoted by V_{fix}, V_{true}, and d_{fix}, d_{true}, respectively. The methodology assumes that the center of the fixed VOI nearly coincides with that of the actual lesion.

If the actual lesion diameter were known, it would be theoretically possible to calculate the actual AD based on the minimum AD. Therefore, a correction factor exists that is multiplied by the minimum AD to yield the actual value. Two effects contribute to the correction factor: particle range and partial-volume effects. First, if the lesion size approaches a value of approximately less than 10 mm, the range effect of β particles emitted by ^{131}I cannot be longer ignored, which effectively decreases the ADs to the lesions (Stabin et al., *J Nucl Med.* 2000;41:149–160; Li et al., *Radiat Res.* 2001;156:419–429; Champion et al., *J Nucl Med.* 2008;49:151–157). The AD fractions (φ) at different true diameters have recently been parameterized (Jentzen et al., *Q J Nucl Med Mol Imaging.* 2011;55:21–43); the AD fractions at different sphere diameters are listed in Supplemental Table1.

Second, the partial-volume effect is a consequence of the limited PET spatial resolution. The partial-volume effect can be corrected for using a recovery coefficient (RC), which is the ratio of the imaged to the true activity concentration. The imaged activity concentration is often the maximum activity concentration of an imaged lesion or the more appropriate average activity concentration (Jentzen et al., *Q J Nucl Med Mol Imaging.* 2011;55:21–43; Jentzen W, *Phys Med Biol.* 2010;55:2365–2398). The average activity concentration is termed the isovolume activity concentration, and its corresponding RC is termed the isovolume RC (Jentzen W, *Phys Med Biol.* 2010;55:2365–2398). In the present study, a fixed-volume RC is additionally required to calculate the effective correction factor. The imaged activity within the fixed VOI (A_{fix}) containing the lesion with actual diameter of $d_{true} < d_{fix}$ divided by the fixed volume is referred to as fixed-volume activity concentration ($I_{fix} = A_{fix}/V_{fix}$). The corresponding fixed-volume RC (RC_{fix}), then, is the ratio of the fixed-volume activity concentration to the true activity concentration ($C = A_{true}/V_{true}$) and is a function of the true lesion diameter. The fixed-volume RC was determined by simulation using a sphere model and a 3-dimensional Gaussian-shaped point-spread function (Jentzen W, *Phys Med Biol.* 2010;55:2365–2398). In the imaging model, the sphere contained a uniform activity concentration and was embedded in a zero background (or a high signal-to-background ratio). Note that the fixed-volume RC is

identical to the isovolume RC if the actual lesion diameter accidentally coincides with the fixed diameter. The fixed-volume RCs were simulated for various actual diameters (2–11.5 mm) for a fixed VOI of 0.80 mL (lower limit of determinability of the applied volume segmentation method) and a PET spatial resolution of 8.2 mm, which was the spatial resolution of the PET system used in this study. The activity ratios of A_{fix} to A_{true} and the fixed-volume RCs are listed in Supplemental Table 1.

In estimating the minimum AD, the partial-volume effect correction was performed using an isovolume RC, $RC_{iso}(d_{fix})$, of a sphere 11.5 mm in diameter. Also, the particle range effect was neglected in the minimum-AD estimation, i.e., the AD fraction was unity. Taking into account the partial-volume and particle range effects, a correction factor could be calculated as a function of the actual diameter. The true-to-minimum AD ratios (D_{true}/D_{min}) are listed in Supplemental Table 1 for actual lesion diameter ranges of 2–11.5 mm. This correction factor is dominated by the volume ratio of V_{fix} to V_{true} (not listed in Table 1) followed by the activity ratio of A_{fix} to A_{true} and the AD fraction. Two remarks should be made. First, the correction factor is unity if the actual lesion volume coincidentally equals the fixed volume. Second, sometimes the lesion size may be discernible in morphologic imaging, such as ultrasonography, CT, or MR tomography. In this case, an improved estimation of the AD can be obtained using the correction factors listed in Supplemental Table 1.

SUPPLEMENTAL TABLE 1

Simulated Correction Factors at Various Actual Lesion Diameters (D_{true}) and the Minimum ADs of Lesions Below
11.5 mm to Achieve 85 Gy for Metastases (Mets.) or 300 Gy for TRs

d_{true} (mm)	Particle-range effect ϕ[a]	Partial-volume effect A_{fix}/A_{true}[b]	Partial-volume effect RC_{fix}[c]	Correction factor (D_{true}/D_{min}) $\phi \cdot RC_{iso}/RC_{fix}$	Minimum AD (Gy) Mets. (85 Gy)	Minimum AD (Gy) TRs (300 Gy)
2.0	0.78	0.557	0.003	97.6	1	3
2.5	0.83	0.553	0.006	51.9	2	6
3.0	0.86	0.547	0.010	32.3	3	9
3.5	0.88	0.542	0.015	22.0	4	14
4.0	0.90	0.535	0.023	14.7	6	20
4.5	0.90	0.527	0.032	10.7	8	28
5.0	0.92	0.519	0.043	8.0	11	38
6.0	0.94	0.500	0.071	5.0	17	60
7.0	0.95	0.479	0.108	3.3	26	91
8.0	0.95	0.456	0.153	2.3	37	130
9.0	0.96	0.431	0.206	1.7	50	176
10.0	0.97	0.404	0.266	1.4	61	224
11.0	0.97	0.377	0.330	1.1	77	273
11.5	1.00[d]	0.364	0.364[e]	1.0	85	300

[a]Parameterized value taken from Jentzen et al. (*Q J Nucl Med Mol Imaging.* 2011;55:21–43).

[b]Simulated activity fraction of the imaged (A_{fix}) within the fixed VOI of 0.80 mL to the true activity (A_{true}).

[c]Activity concentration-based fixed-volume RC. In the simulation, a spatial resolution of 8.2 mm was used.

[d]AD fraction was assumed to be unity for the fixed volume.

[e]Value equals the isovolume RC for a sphere 11.5 mm in diameter at a 8.2-mm spatial resolution (Jentzen, *Phys Med Biol.* 2010;55:2365–2398).

Jentzen et al.