Evaluation of a Quantitative Dose Comparison Tool for IMRT and Conformal Therapy

Introduction: We evaluated a dose comparison tool that can be used to evaluate measured and calculated dose distributions(1). The tool can be used to evaluate dose calculation algorithms by comparison against measurements, or calculations against calculations. The tool is based on a generalization of the dose-difference and distance-to-agreement tools recently described by Harms *et al.*(2) and is a measurement of the disagreement between a *reference* distribution and an *evaluated* distribution where the reference distribution can be as sparse as a single point or as large as a volumetric dataset, and the evaluated distribution is at least a one-dimensional dataset. The tool is computed independently for each reference point and is evaluated in a generalized space consisting of the distance and dose difference between the reference point and the evaluated distribution points. The distance and dose axes are normalized to a distance-to-agreement and dose-difference test criteria, respectively, so the axes are unitless. The minimum distance in this normalized space is labeled by the symbol γ. **The comparison passes if g≤1 and fails if g>1**.

The original description of this tool appeared in Low *et al.*(1) which contained a simple example based on a one-dimensional dose distribution intended to mimic a megavoltage beam open field profile. An unadjusted profile was used as the reference distribution, while the evaluated distribution was the same profile altered to model a positional offset, a dosimetric offset, and a combination of the two. The original study did not address the influence of the **pixel size, criteria selection, or measurement noise** on the results. This presentation will detail our work on evaluating the influence of these criteria on the selectivity of the tool.

The test experiments are all conducted in two dimensions and use a model of an open 10 x 10 cm^2 megavoltage field (Figure 1) with 2.0 x 2.0 mm^2 pixels. The field is divided into four quadrants, and the reference distribution remains unaltered. The evaluated distribution, however, is adjusted as a function of the quadrant (Figure 2).

    Quadrant 1: Reference and evaluated distributions equal

    Quadrant 2: Evaluated distribution shifted in position orthogonal to the field edge

    Quadrant 3: Evaluated distribution is modified by an additive dose error as a function of the off-axis distance parallel to the field edge, providing an evaluation of γ for variations of dose magnitude, rather than position.

    Quadrant 4: Combination of the dose and position shifts is applied.

Figure 3 shows the dose difference between the reference and evaluated distributions. Figure 4 shows the value of γ with 3% and 3 mm criteria. Because two-dimensional distributions are difficult to quantitatively evaluate, a cumulative histogram is prepared as a function of γ.

Pixel Size: In regions of high dose gradient, the value of γ can be incorrectly determined because of the rapid change in dose as a function of position. For example, in a one-dimensional case if two distributions are exactly the same, but are offset by a half a pixel with width Δx, the calculation of γ will take place in the neighboring pixel centers, and the error in the calculation of γ will be $dg \leq \dfrac{\Delta x}{2} \dfrac{\nabla D}{\Delta d}$ where ∇D is the gradient of the dose distribution, and Δd is the dose-difference criterion. Therefore, in these examples, the evaluated distribution was bilinearly interpolated to locate the point corresponding to the minimum distance in the combined space. While mathematically, given the maximum value of the gradient in these examples, the pixel spacing should have been 0.1 mm, the nature of the gradient was such that interpolation to only 0.25 mm was required.

Criteria: Figure 5 shows a cumulative γ histogram for quadrant 2 (shifted distribution). The histogram present for two identical distributions consists of a peak at γ=0 with zeros beyond. The purpose of this analysis was to determine the effects of changing criteria (dose-difference and distance-to-agreement acceptable errors) on the γ distribution when the two dose distributions disagreed by a spatial shift, with all combinations of 1.5mm and 3mm and 1.5% and 3% tested. For the shifted distribution, all of the area where γ>1 was in the penumbra region (see Figure 4). The influence of reducing the distance-to-agreement criterion by half was more pronounced than reducing the dose-difference criterion, as shown in Figure 5.

Noise: The effects of adding pseudorandom noise are illustrated in the γ histogram shown in Figure 6. Three of the lines are highlighted, no noise (solid), 4% noise added to the reference distribution (dashed) and 4% noise added to the evaluated distribution (short dashed). The influence on the γ histogram is clearly more significant when noise is present in the reference distribution than in the evaluated distribution, leading to the conclusion that when noise is present in the reference distribution, some effort should be made to smooth the noise to much less than the dose-difference criterion.

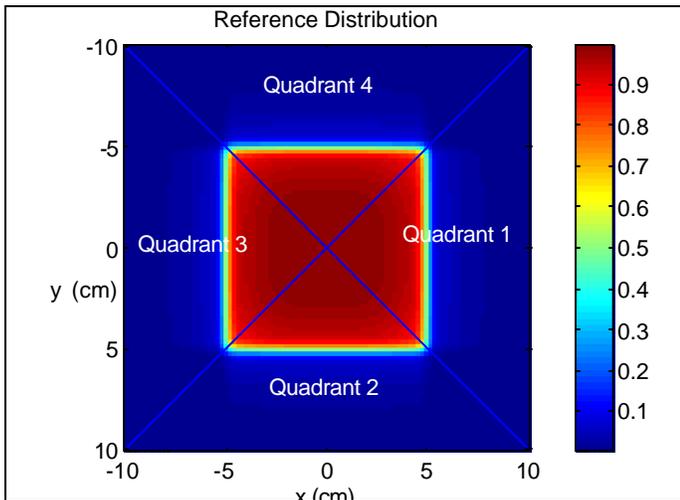Evaluation of a Quantitative Dose Comparison Tool for IMRT and Conformal Therapy

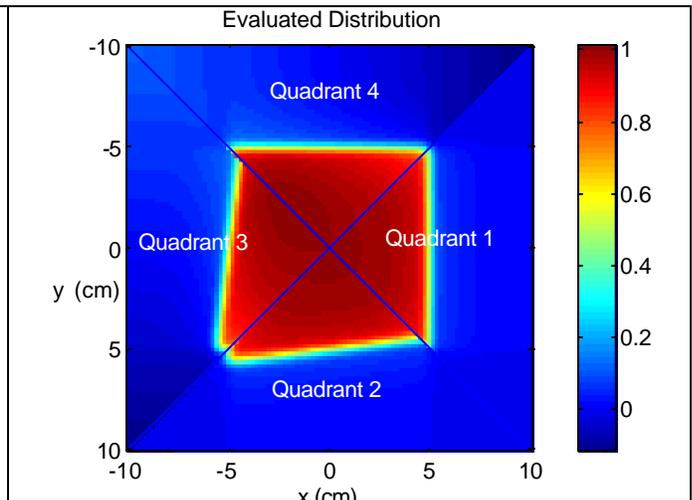Figure 1: Reference Dose Distribution

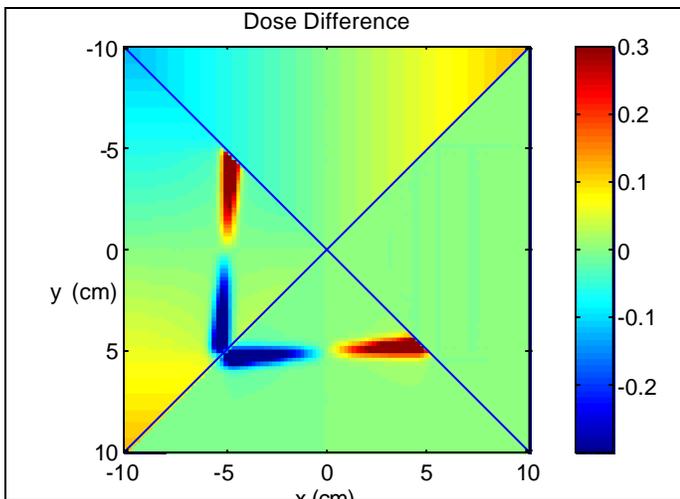Figure 2: Evaluated Dose Distribution

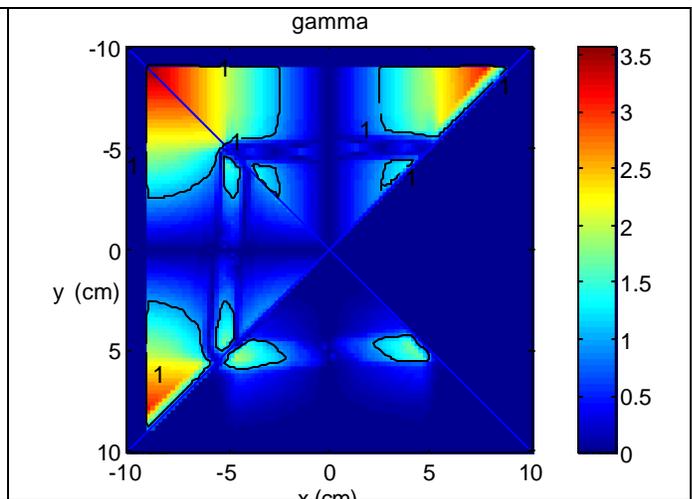Figure 3: Dose Difference between Figs 2 and 1

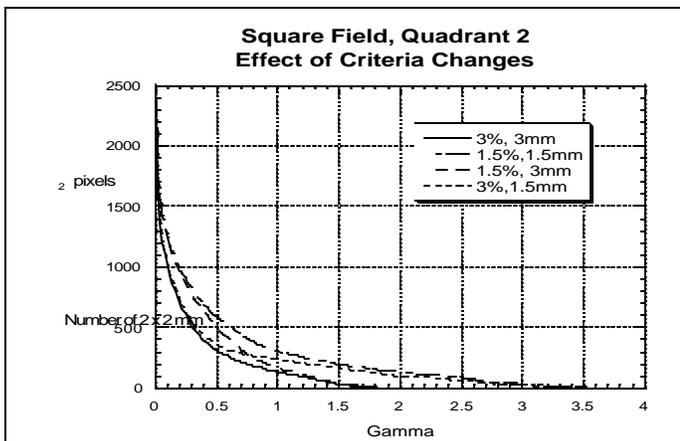Figure 4: γ for comparison between Figs 2 and 1

Figure 5: Cumulative γ histogram for Quadrant 2 of Fig 4, adjusting acceptance criteria
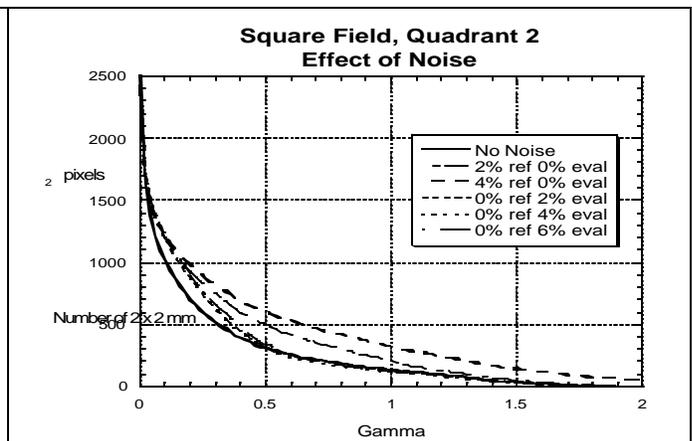

Figure 6: Cumulative γ histogram for Quadrant 2 of Fig 4, adding pseudorandom noise to reference and eval distributions.

References:

[1] D. A. Low, W. B. Harms, S. Mutic, and J. A. Purdy, "A technique for the quantitative evaluation of dose distributions," Medical Physics **25**, 656-61 (1998).

[2] W. Harms, D. A. Low, J. W. Wong, and J. A. Purdy, "A software tool for the quantitative evaluation of 3D dose calculation algorithms," Medical Physics **25**, 1830-6 (1998).