

## A potential modification of the $\gamma$ -evaluation: mapping dose disagreements using $\gamma$ -vector fields

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**Abstract.** This work describes the use of a motion phantom and 1D, 2D, and 3D ion chamber, EBT3 film, electronic portal imaging device (EPID) and FXG gel measurements for dosimetric validation of a stereotactic ablative radiation therapy (SBRT) technique in our clinic. Results show good agreement between the measurements and calculated treatment plan dose.

### 1. Introduction

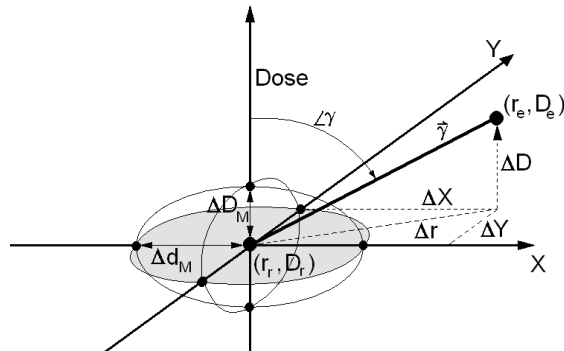
Gamma evaluations [1] are a preferred clinical tool used in the validation of dose delivery in modern radiation therapy. The gamma comparison provides a quantitative comparison between dose-distributions, combining both dose difference and distance to agreement criteria. The gamma evaluations permit rapid analysis and visualization of the agreement between complex dose distributions.

A gamma comparison is performed between two dose maps: one distribution is the reference plan (typically from a treatment planning system) and the other is the evaluated distribution usually from a two or three-dimensional dose measuring system. The reference image is treated as the true distribution, while the evaluated image is analyzed for its agreement with the reference as follows: Every point in the reference image has a corresponding  $\gamma_r$  value; a measure of agreement at that location. Each possible point in the reference distribution,  $r_r$ , can be coupled with any point in the evaluated image,  $r_e$ . For all pairs a value  $\Gamma_r$ , defined by the vector difference between the points, exists. Tolerance criteria  $\Delta d_M$  and  $\Delta D_M$  (e.g., 3mm and 3%) are used to normalize  $\Gamma_r$  along the distance and dose vector dimensions, correspondingly. The gamma index value,  $\gamma_r$ , is the smallest  $\Gamma_r$  that can be found considering the entire evaluated distribution. In the image space,  $\Gamma_r^2=1$  describes an ellipsoid whose surface is defined by the tolerance criteria (figure 1). When  $\gamma_r \leq 1$  the distributions agree within the stipulated tolerances. Conversely, when  $\gamma_r > 1$ , no point in the evaluated distribution can be found within the ellipsoid and the dose distributions disagree at that location.

Although the  $\gamma$  comparison provides a useful measure of agreement between distributions when the index is less than one, the scalar gamma value provides little information into the clinical significance or source of disagreements of failing gamma values (i.e., when  $\gamma > 1$ ). Stock *et al* [2] previously presented the gamma angle as an indicator of the relative influence of the distance to agreement versus the dose difference on gamma. This angle represents only a portion of the available vector information. In this work, we present a modification to the gamma evaluation such that the complete



gamma vector information for 2D comparisons is calculated. We will also present an initial analysis of the influence of various dose disagreements on the resulting vector field.



**Figure 1:** A graphical representation of gamma between a point on the reference distribution  $r_r(r_r, D_r)$ , and a point in the evaluated distribution  $r_e(r_e, D_e)$ . The figure illustrates the vector property of the  $\gamma$  evaluation.

## 2. Methods and Results

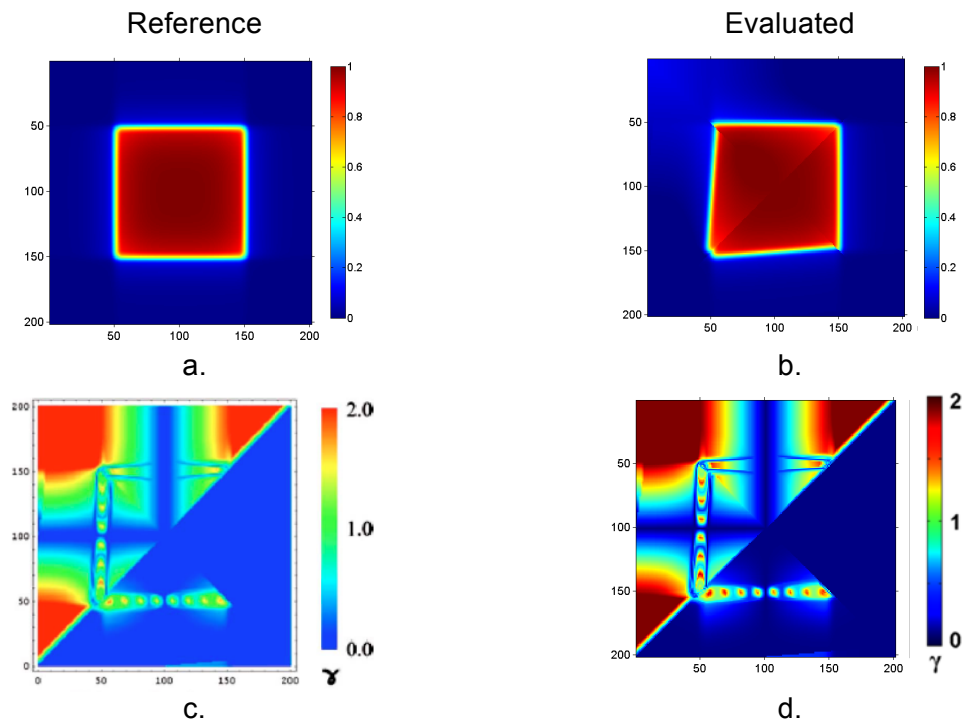
Gamma comparisons were performed using in-house software written in MATLAB (Mathworks, Newark, NJ). The tool calculates the magnitude of gamma, as usual, but also returns the corresponding vector information. The result for a 2D comparison is a 3D vector field comprised of two distance and one dose dimensions. Therefore, gamma vectors for 2D comparisons have three components,  $\Delta X$ ,  $\Delta Y$  and  $\Delta D$ ; each is normalized to the tolerance criteria (e.g., 3%3mm). The distance to agreement portion of gamma,  $\Delta r$ , is broken into its constituent spatial components  $\Delta X$  and  $\Delta Y$ , while  $\Delta D$  alone represents the dose difference contribution. The gamma algorithm used in this evaluation is similar to one presented previously [3]. However, in the current implementation neither interpolation nor geometric methods are employed to avoid the overestimation of gamma in regions of high dose gradient: a well known limitation that is caused by discrete, pixelized, representations of truly continuous dose distributions [3, 4].

The  $\gamma$ -vector evaluation tool was assayed on test images under a variety of manipulations. Each test, involved modifying the original distribution (to provide the evaluated distribution) and comparing it back to the original unmodified image (the reference). Initial tests involved the test distribution originally implemented by Low<sup>1,4</sup> (figures 2 and 3). Results will also be shown of tests in which the evaluated image was uniformly shifted along each of the three image dimensions one at a time (dose is the third dimension). The net effect of each misalignment was measured by calculating the mean value of each gamma component over the entire  $\gamma$ -vector map. Vector gamma analysis of simulated dose errors (in the form of double Gaussians doses added into a head and neck distribution at separate locations corresponding to the surrounding tissue, a target, an avoidance structure, and the target boundary area will be reported to provide more clinical examples (figure 4).

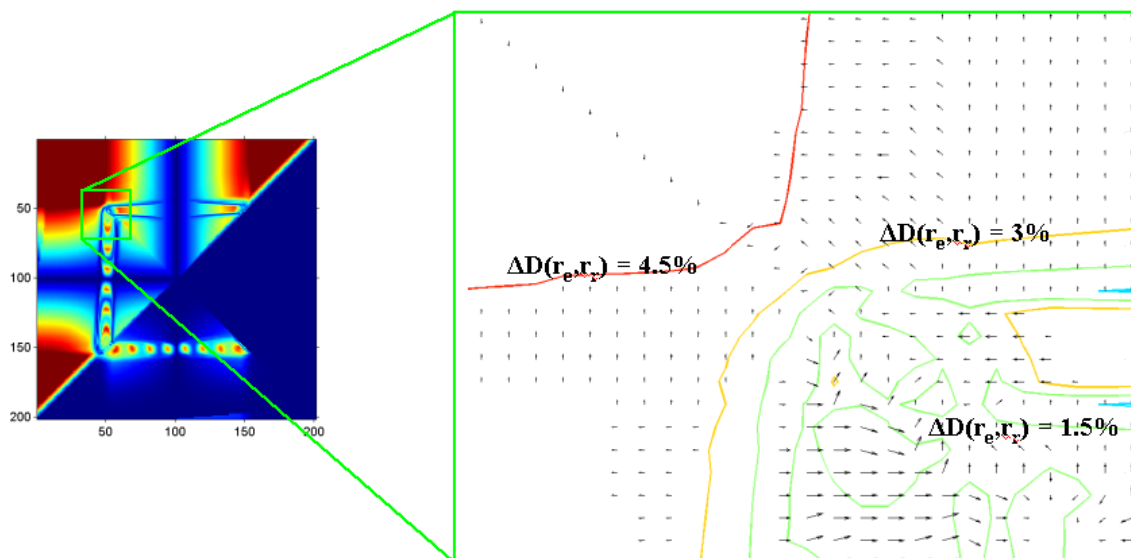
## 3. Results and Discussion

Our implementation of  $\gamma$  provides magnitude data consistent with the original test (figure 2). For tests in which the perturbation of the initial reference distribution was generated by a spatial misalignment, the spatial gamma component,  $\Delta r$ , clearly dominates the dose component,  $\Delta D$ . The different response of the two distributions under identical manipulations indicates that exact behaviour of the resulting vector field depends on the unique properties of each distribution. Nevertheless, the response of the vector field shows the same trends regardless of the image under investigation.

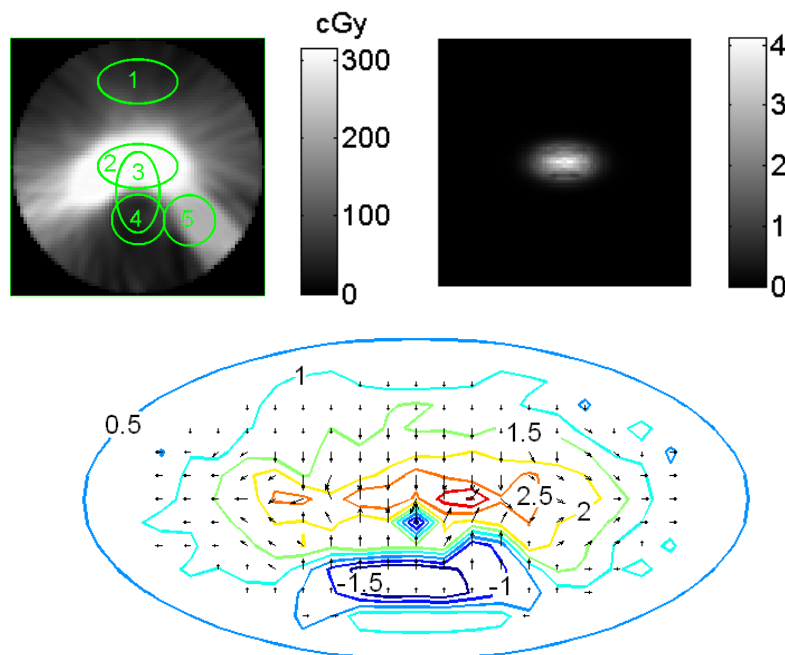
In figure 4, there are two small regions where  $\Delta D$  is negative which was unexpected because the disagreement was due to a known overdose. A closer examination of the reference image revealed that the unexpected negative regions were caused by variations in the local dose gradient. Therefore, a weakness in our current implementation of gamma is the sensitivity to dose gradients. A more robust implementation of gamma using geometric or interpolation methods may obviate this effect altogether.



**Figure 2:** Gamma comparisons between test distributions used by Low and Dempsey (2003). (a) the reference distribution. (b) the evaluated distribution. (c) gamma magnitude distribution calculated with the original  $\gamma$ -tool (reproduced with permission<sup>5</sup>). (d) gamma magnitude distribution calculated with the new in-house  $\gamma$ -tool.



**Figure 3:** The  $\gamma$ -vector evaluation yields the same magnitude plot (Left), as well as the corresponding  $\gamma$ -vector information in component form (Right). The vector information shown on the right corresponds to the rectangular ROI on the top left corner of magnitude plot. The voids in the vector plot occur when the spatial components of  $\gamma$  are zero in magnitude..



**Figure 4:** Top Left: A clinical head and neck distribution (simulated using in-house planning software) with five regions of interest highlighted. Top Right: When a double Gaussian 15% overdose is added to region 2 in the evaluated image a typical 2D gamma plot shows only the magnitude of the gamma vector. The enlarged gamma vector plot at the bottom corresponding to the 15% overdose in region 2 is shown above. The arrows represent the  $\Delta X$  and  $\Delta Y$  contribution while dose component,  $\Delta D$ , is indicated by the contour lines.

#### 4. Conclusions

The gamma vector field contains information that could be useful in identifying the cause and significance of dose disagreements between plan and delivery that fail the acceptance criteria. The response of the vector field depends on properties distinctive to each distribution, such as the local dose gradient. Further analysis is underway to improve the implementation.

#### 5. Acknowledgements

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#### 6. References

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