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Original paper

Statistical analysis of the gamma evaluation acceptance criteria: A simulation study of 2D dose distributions under error free conditions

Svjetlana Sunjic[a,*], Crister Ceberg[b], Tomislav Bokulic[c]

[a] Radiation Safety and Medical Physics Department, University Clinical Centre Sarajevo, Bolnicka 25, 71000 Sarajevo, Bosnia and Herzegovina
[b] Division of Medical Radiation Physics, Department of Clinical Sciences Lund, Lund University, 221 85 Lund, Sweden
[c] Dosimetry Laboratory, Dosimetry and Medical Radiation Physics Section, International Atomic Energy Agency, Friedenstrasse 1, Seibersdorf, Austria

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ABSTRACT

Purpose: To investigate the statistical distribution of the gamma value under error-free conditions, in order to study the relation between the gamma evaluation failure rate and statistically significant deviations in the general situation.

Methods: The 2D absorbed dose distribution for 30 clinical head-and-neck IMRT fields were calculated in a QC phantom. For the same fields, dose measurements were simulated by assuming that the calculated value represented the expectation value, and by adding a random spatial uncertainty of 1–9 mm (1SD) and a random dose uncertainty of 1%–3% (1SD). The simulated measurements were then compared to the calculated dose using the gamma evaluation, and the distribution of the failure rate (i.e. the probability of gamma values above unity) was analysed.

Results: For a wide range of the random measurement uncertainty, a distinct peak in the failure rate distribution was observed. The presence of higher failure rates was associated with large values of the second order derivative of the dose distribution. For spatial uncertainties larger than or equal to the resolution of the dose matrix, and for reasonable dose uncertainties, the median value of the failure rate distribution was fairly constant.

Conclusions: Simulations showed, in the general case, that the probability of having a gamma value above unity under error-free conditions was not spatially uniform. We believe that this shortcoming may be partly responsible for the limited ability of the gamma evaluation method to detect errors in clinically relevant situations.

1. Introduction

Advanced dose delivery techniques like intensity modulated radiation therapy (IMRT) and volumetric arc radiation therapy (VMAT) requiring sophisticated treatment planning systems (TPS) have improved modern radiation therapy by enabling radiation oncologists to achieve improved target volume dose conformity and localization accuracy while sparing surrounding normal tissues. These improvements have considerably increased the requirement for dose delivery verification, especially in the commissioning of radiotherapy treatment units and new treatment techniques, and during the patient specific validation of the dose delivery [1,2].

Early attempts of comparing the dosimetric and spatial information in two dose distributions, commonly referred to as the *reference* (e.g. calculated) and *evaluated* (e.g. measured) dose distribution were intuitive and straightforward. They involved simple overlaying of dose contours in various planes for comparison. An alternative proposed was the comparison by calculating a spatial distribution of the numerical percentage difference in the doses in these two distributions. A shortcoming with this technique is that the approach is inherently oversensitive in regions of high dose gradient where small spatial uncertainty in either distribution data set can lead to large dose differences between the measured and calculated distributions, without having a real clinical significance. Another method, the use of the distance to agreement (DTA) measure, which expresses the distance between the calculated point and the nearest point in a measured dose distribution with the same dose value [3,4], is needed to obtain useful comparisons in regions of high dose gradient. However, while DTA maps work well in regions of high dose gradient, they tend to be excessively sensitive in regions of low dose gradients where only a small difference may correspond to a very large DTA.

To overcome this deficiency, a composite of these two measures (dose difference and DTA), which shows only regions that fail both criteria, was introduced [3]. In high-dose gradient regions, the dose difference distribution yields large values for small spatial offsets between the compared dose distributions. The DTA analysis returns the

* Corresponding author.
E-mail addresses: svjetlana.sunjic@kcus.ba (S. Sunjic), crister.ceberg@med.lu.se (C. Ceberg), t.bokulic@iaea.org (T. Bokulic).

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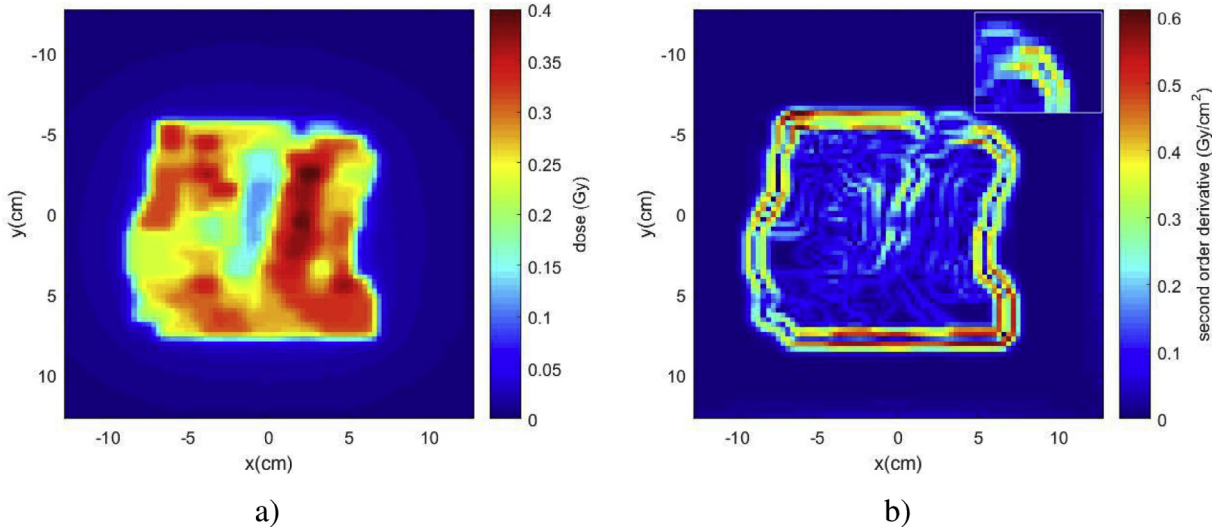

Fig. 1. (a) Absorbed dose distribution at 5 cm depth calculated using the TPS for a real clinical IMRT study, (b) the map of the corresponding second derivative values of the dose distribution shown in (a) with an enlarged map area in the upper right corner.

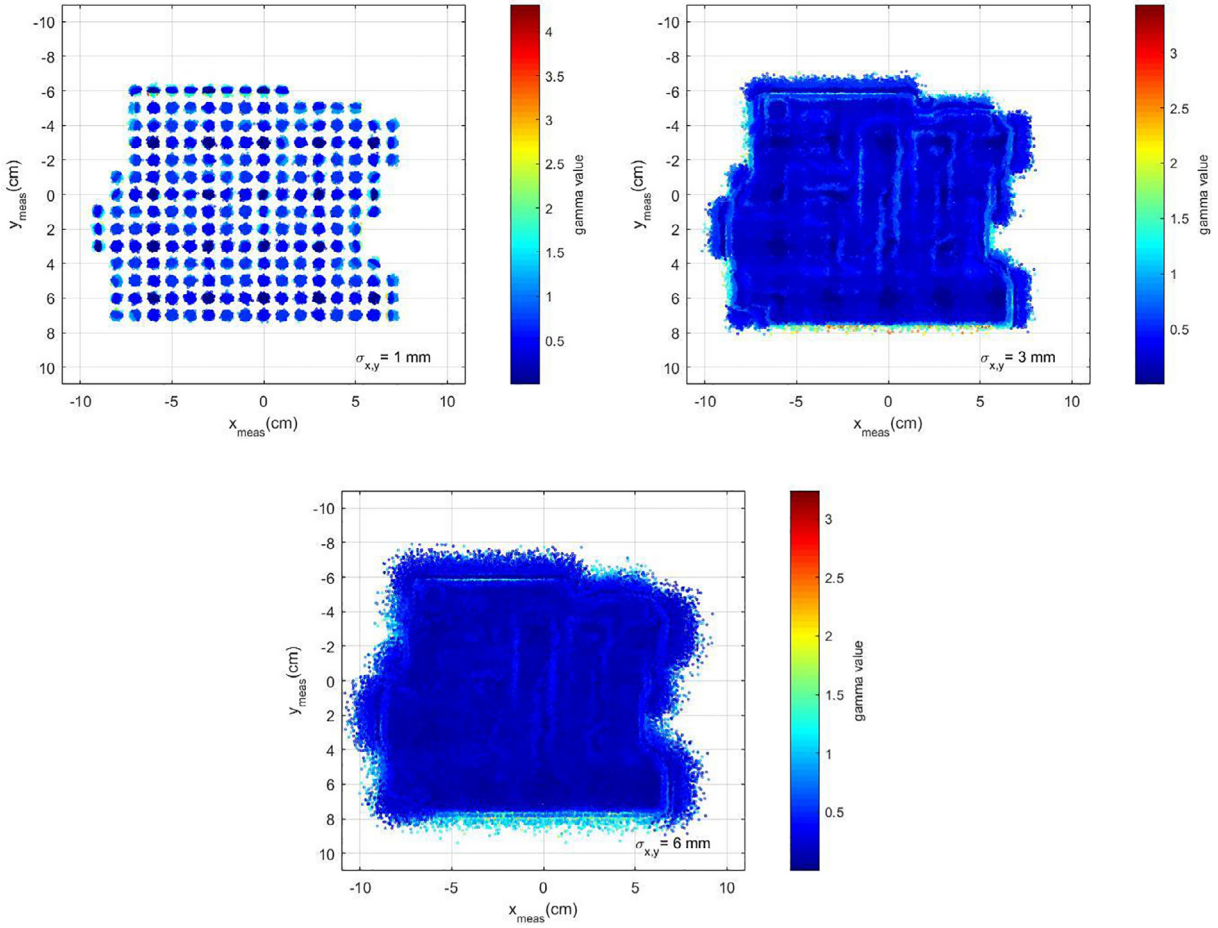

Fig. 2. Spatial distributions for gamma index values calculated per point for the whole 19 × 19 matrix of simulated detector positions, shown as a function of the measured coordinates x and y. The calculations were carried out for 1, 3 and 6 mm spatial uncertainty.

approximate spatial difference between the two distributions. If the spatial offset is less than the criteria, the DTA analysis will pass, and the algorithm will have passed the composite analysis. The analysis does not indicate by how much the test is passed or failed. To further address the limitations of the composite distribution for the evaluation of comparisons of two distributions, one reference distribution (e.g. from a treatment planning system) and the other, evaluated distribution usually from a 2D or 3D dose measuring system, the so-called gamma-evaluation method was developed [5,6]. For the comparison of a given measurement point and any one of the calculation points, a generalized Euclidian distance can be calculated according to: