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Introduction of a Reliable Software for the Calculation of the Gamma Index

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ABSTRACT

Introduction: The gamma index is a known parameter for radiotherapy dose verification. Many free and commercial programs have been written for the calculation of this index. However, the verification of the results has been overlooked in many of the programs. The present study tested the validity of three gamma index calculator programs.

Material and Methods: The gamma indices for three measured and calculated dose distribution pairs presented in Low et al., Medical Physics, (1998) were calculated using three programs to compare with the results of the published paper. They included an executable program working in Gnuplot software environment (i.e., Gamma_index.exe), simple implementation of the formulas by MATrix LABoratory (MATLAB) software (i.e., Simple m-file), and CalcGamma MATLAB-based program distributed at GitHub website (i.e., Geurts). The resulted gamma distributions were compared with the three figures of the study by Low et al.

Results: According to the results, it was observed that neither Gamma_index.exe nor Simple m-file calculated gamma indices was valid, with up to 31% difference in pass rates. On the other hand, Geurts showed fairly good agreement with the gamma indices presented in Low et al. paper.

Conclusion: Use of gamma index calculator programs, such as Gamma_index.exe should strongly be prohibited without verification. Furthermore, the implementation of the gamma index formulas without enough preprocessing of the data results in invalid values. Geurts is a reliable program that can be used in its current form or it can be changed to stand-alone executable software for the use in studies and clinics.

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Introduction

Low et al. introduced a quantitative measure for the comparison of the measured and calculated dose distributions in 1998 [1]. This quantitative measure has been extensively used in dosimetric practices and researches so far. The gamma (γ) index allows simultaneous dose distribution comparison along dose and distance axes. Two acceptance criteria were named as dose-difference (DD) and distance-to-agreement (DTA) which are the normalizing factors for the distances along dose and distance axes, respectively.

The γ values more than 1 indicate the test failure. Low et al. showed the applicability of the γ quantity in two-dimensional (2D) dose comparisons [2]. It can also be used for the quantitative comparison of measured and calculated dose distributions for commissioning of a three-dimensional (3D) treatment planning system [3]. Importance of this measure in one-dimensional (1D), 2D, and 3D dose comparisons for clinical and investigational use resulted in the development of many commercial and free dose evaluation programs.

One of the extensively used software programs to calculate γ of two 1D dose distributions is an executable program named as Gamma_index.exe working in Gnuplot software environment. It will be referred to as Gamma_index.exe later in the text. This software is widely used by medical physics and medical radiation engineering students for measured and/or simulated data verification.

Application of Gamma_index.exe software is straightforward through the use of two text files, including the spatial information in one column and dose in the other. A one-line command in the command window containing the two data files and DD and DTA acceptance criteria results in the DD, DTA, and gamma index values as .DAT files. In addition, the resulted values can be plotted using Gnuplot software provided in the package.

Because film dosimetry is a usual method for 2D dose verification, some codes have been written, especially using MATrix LABoratory (MATLAB) software by the equations presented in Reference [1]. These m-files implement a 1D, 2D, or 3D search within all dimensions of the data to calculate the relative

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distances along the dose and distance axes considering the predetermined DD and DTA criteria. For each measured (reference) data point, the least calculated gamma within the calculated (evaluated) dataset is assigned to that point. Finally, the points with $\gamma \leq 1$ indicate passed points, and others demonstrate failed points. Gamma2d.m program is one of these freely available codes [4] extensively used by investigators and medical physicists. The corresponding 1D version is referred to as Simple m-file in the present text.

Mark Geurts affiliated to the University of Wisconsin Board of Regents distributed an m-file in 2014, written by MATLAB software, on the GitHub website for the calculation of 1D, 2D, and 3D gamma indices [5]. It is a function in which two structures should be provided as the reference and target datasets as well as DD and DTA acceptance criteria. In addition, some optional parameters can be set to make the program run faster. It contains 687 code lines with suitable comment lines that makes it understandable for the users familiar with MATLAB software. This MATLAB-based function is referred to as Geurts in the text.

Low et al. [1] in their study provided three sets of calculated 1D dose profiles and a measured dataset, as well as the corresponding gamma distributions. They can be used for the verification of the gamma calculation programs. Therefore, the present work studied the resulted gamma indices calculated using Gamma_index.exe, Simple m-file, and Geurts programs in comparison to γ distributions provided by Low et al. [1], later referred to as Low gamma.

Materials and Methods

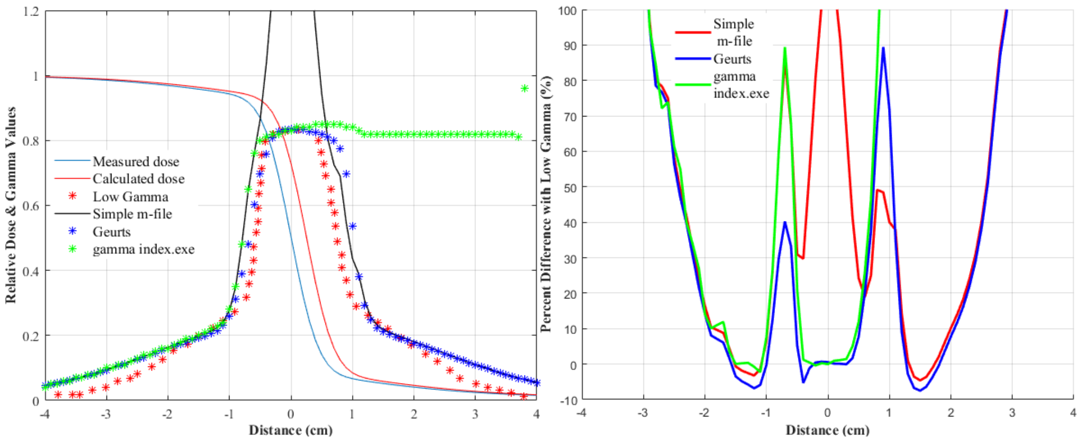
Three calculated dose profiles, as well as a measured dose profile, are provided in figures 4, 5, and 6 of Reference [1]. The first pair models a 0.25 cm spatial shift between calculation and measurement; while, the second pair adds a 2.5% normalization difference. The third pair models a 0.25 cm spatial shift and 2.5% dose offset between calculation and measurement. They were reproduced using the error function and fitting constants as provided by equations (9) and (10) in Reference [1] by MATLAB software (R2017a, MathWorks Inc., Natick, MA). The resulted γ distributions were digitized based on part (b) of the aforementioned figures to provide the Low gamma dataset.

The data points with 1 mm resolution were produced and fed as two text files into Gamma_index.exe program. The Gamma2d.m file was modified to be used as a gamma calculation tool for 1D dataset, and the input variables were fed into it. Finally, the calculated and measured dose variables were changed to an acceptable format for the Geurts program.

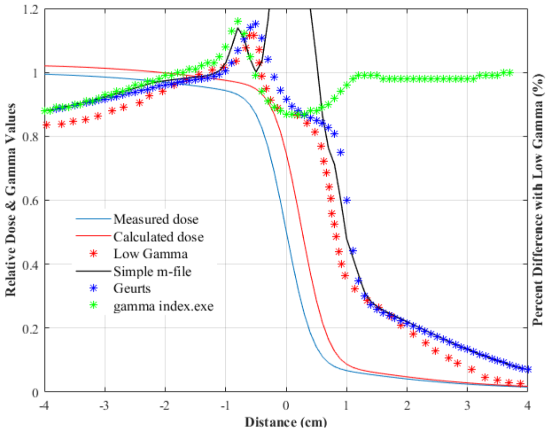
In all gamma calculations, 3% and 3 mm DD and DTA acceptance criteria were used in accordance with the results of the study by Low et al. [1]. The points with $\gamma > 1$ indicate positions in which the measured and calculated dose distributions do not agree. The calculated γ distributions, as well as Low gamma, in addition to their percentage difference, are shown in Figure 1. It should be noted that Low gamma curve was obtained by xyExtract software (Campina Grande, Paraíba, Brazil) [6] because the exact data points were not available. The xyExtract software is used to extract data from a 2D graph presented as a bitmap file.

Results

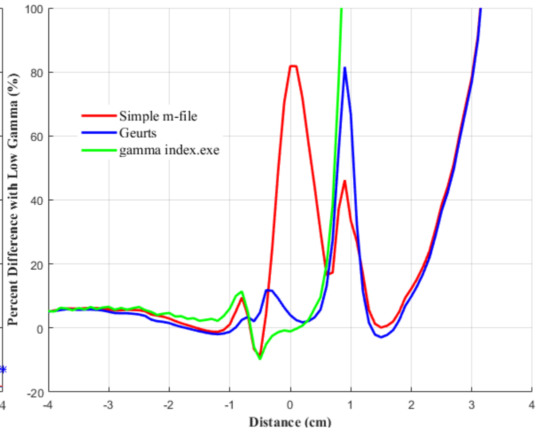
Parts (a), (c), and (e) in Figure 1 depict the measured and calculated dose profiles as provided in figures 4, 5, and 6 in the study by Low et al. [1], respectively. Moreover, Low gamma, Simple m-file, Geurts, and Gamma_index.exe calculated γ distributions are shown in the aforementioned figures. Parts (b), (d), and (f) in Figure 1 illustrate the corresponding percentage difference of each calculated γ distribution with Low gamma. It should be noted that Low gamma was subtracted from the calculated ones divided by Low gamma; therefore, negative values indicate underestimated γ values and vice versa.



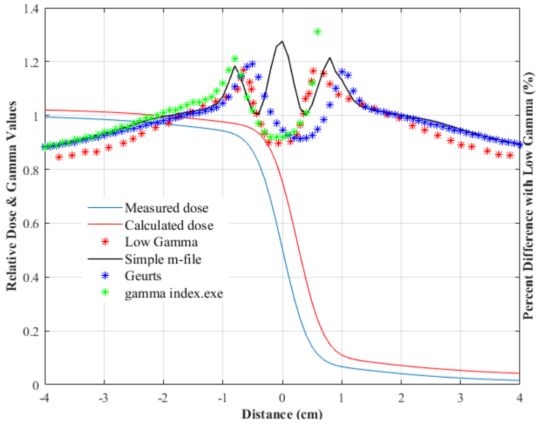
(a) (b)



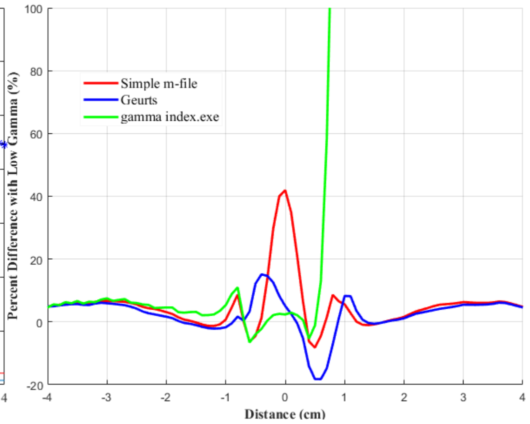
(c)



(d)



(e)



(f)

Figure 1. Measured and calculated relative dose profiles reproduced from the study by Low et al. and the corresponding digitized gamma distributions from Reference [1] (Low Gamma) and calculated using Simple m-file, Geurts, and Gamma_index.exe for figures (a) 4, (c) 5, and (e) 6 in Reference [1] and their corresponding percentage errors in (b), (d), and (f) parts.

Discussion

Parts (a), (c), and (e) of Figure 1 show that although Gamma_index.exe calculated γ is fairly acceptable in comparison to Low gamma in the negative half of the x-axis; it overestimated the γ value on the positive side. The Simple m-file did not match to Low gamma on the central axis where there is a high dose gradient in the measured and calculated dose distributions. Therefore, neither the calculated gamma values by Gamma_index.exe nor Simple m-file is acceptable and reliable.

On the other hand, Geurts program showed an acceptable agreement with Low gamma. Table 1 is provided in order to make a quantitative comparison between the three γ calculators. Table 1 tabulates the minimum, maximum, absolute mean, and median of percentage differences. Furthermore, the difference between the pass rates of each calculated γ distribution with Low gamma is presented in Table 1 because normally the main purpose of γ index calculation is reporting the pass rate (i.e., the ratio of points with $\gamma \leq 1$ to all points).

Table 1 shows that the performance of Gamma_index.exe program was almost the worst case among the other two competitors. Although Geurts program showed the highest minimum difference with Low gamma in two cases, it demonstrated the lowest maximum, mean, and median difference with the reference dataset for all three cases. The Simple m-file showed a performance in between. Last column of Table 1 complemented the other columns. The Simple m-file and Gamma_index.exe programs suffered from the overestimation of γ index (i.e. negative pass rate difference), for example, 31% lower pass rate by Gamma_index.exe than Low gamma for Figure 1 (f).

On the other hand, Geurts program overestimated the pass rate in two-thirds of the cases but with a low difference of 1% (i.e. 1 point among 81 data points). Remembering that Low gamma curve was digitized from the provided figures, it can be concluded that complete agreement between the γ calculators may not be accomplished. However, the dramatic difference of Gamma_index.exe with the expectation and acceptable performance of Geurts encourages the substitution of Gamma_index.exe program with the latter one.

Table 1. Minimum, maximum, absolute mean, and median of the percentage difference between calculated gamma values using Simple m-file, Geurts, and Gamma_index.exe programs with Low gamma, as well as difference of the pass rates. The best and the worst performance among the three programs for each figure is indicated with green and red colors, respectively.

Figures	Programs	Minimum	Maximum	Mean	Median	Δ Pass rate
Figure 1 (b)	Simple m-file	-5	1103	97	53	-11
	Geurts	-8	1103	87	33	0
	Gamma_index.exe	-2	75504	1728	140	-2
Figure 1 (d)	Simple m-file	-9	188	36	6	-10
	Geurts	-3	188	31	6	+1
	Gamma_index.exe	-10	17844	767	7	-6
Figure 1 (f)	Simple m-file	-8	42	6	5	-14
	Geurts	-18	15	5	4	+1
	Gamma_index.exe	-7	6478	818	7	-31

Conclusion

In the present study, the validity of three γ calculation programs were tested against the data provided by the introducer of the γ index. Based on the results obtained from the 1D dose profiles, it is highly recommended to prohibit the use of Simple m-files written based on the equations by Low et al. or Gamma_index.exe program. As a substitute, Geurts program was also tested in the present study, and its acceptable performance in addition to its extension to 3D dataset leads to recommending Geurts program for research and practical purposes. It can be run in its current format by MATLAB software or it can be converted to an executable stand-alone program that is under construction by the authors.

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