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Original article

A tool to include gamma analysis software into a quality assurance program

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ABSTRACT

Purpose: To provide a tool to enable gamma analysis software algorithms to be included in a quality assurance (QA) program.

Methods: Four image sets were created comprising two geometric images to independently test the distance to agreement (DTA) and dose difference (DD) elements of the gamma algorithm, a clinical step and shoot IMRT field and a clinical VMAT arc. The images were analysed using global and local gamma analysis with 2 in-house and 8 commercially available software encompassing 15 software versions. The effect of image resolution on gamma pass rates was also investigated.

Results: All but one software accurately calculated the gamma passing rate for the geometric images. Variation in global gamma passing rates of 1% at 3%/3 mm and over 2% at 1%/1 mm was measured between software and software versions with analysis of appropriately sampled images.

Conclusion: This study provides a suite of test images and the gamma pass rates achieved for a selection of commercially available software. This image suite will enable validation of gamma analysis software within a QA program and provide a frame of reference by which to compare results reported in the literature from various manufacturers and software versions.

Gamma analysis [1] has become the mainstay for patient specific quality control (QC) for intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) as recommended by institutional guidelines for IMRT QC [2–4]. A number of measurement devices (ionisation chamber or diode array), which utilise gamma analysis, are commercially available and have been widely adopted into clinical use. The efficacy of gamma analysis for detecting clinically relevant treatment errors has been disputed [5–9]. However, gamma analysis continues as a readily available, efficient tool to assess the accuracy of large volumes of patient specific treatment deliveries.

Gamma analysis compares the delivered (evaluated) dose distribution point by point to that planned by the treatment planning system (TPS) (reference dose distribution) based on a distance to agreement (DTA) criteria and a dose difference (DD) criteria. Points that pass the set criteria achieve a gamma <1 and the total percentage points passing the criteria for the delivery is calculated. Pass criteria are typically determined within each institution, based on a statistical analysis of the delivery accuracy of patient and test plans delivered within that institution [3]. Various algorithms to calculate the gamma index have been reported and are used in commercially available devices [1,10–17]. The effect of various software implementations of the algorithm can result in different pass rates for a set gamma criteria [18,19]. Image noise and image resolution are also recognised to impact on gamma pass rates [20,21]. Therefore, it is important that each institution understand the influence of their manufacturer's software on their gamma pass rates.

This study provides a suite of test images available electronically with the online published version of this paper. Institutes can freely download these images to assess their manufacturers or in-house developed gamma analysis software at commissioning, post service or following software upgrades and thus incorporate such software into a quality assurance program.

Additionally, the suite of test images can provide a frame of reference to compare results reported from different software versions and different manufacturers in the literature or in multi-centre in-house credentialing audits.

Materials and methods

Four image sets were created, each set comprising an 'evaluated' and a 'reference' image. The dimensions, the pixel pitch

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Table 1
Test image details.

	Geometric test		IMRT field		VMAT arc	
	1 px = 1 mm	1 px = 0.25 mm	1 px = 1 mm	1 px = 0.25 mm	1 px = 1 mm	1 px = 0.25 mm
Image dimension (px)	250 × 250	997 × 997	55 × 86	217 × 314	145 × 193	577 × 769
Total no. pixels	62500	994009	4730	68138	27986	443713
Max. dose (Gy)	5	5	0.908	0.908	0.640	0.640
Complexity (MCS [23])	–	–	0.52	0.52	0.14	0.14

(the distance between the centres of adjacent pixels) and the number of pixels per image are detailed in Table 1. The image sets included:

Geometric DTA test

The 1 mm pixel pitch and 0.25 mm pixel pitch reference images consist of a geometric image of a square measuring 50 × 50 pixels (px) and 200 × 200 px respectively. The 1 mm pixel pitch and 0.25 mm pixel pitch evaluated images consist of a geometric image of a square identical in size and dose, offset laterally and vertically by a fixed distance of 50 px and 200 px respectively in comparison to the reference position. Both images are surrounded by a higher dose rind to prevent auto-matching by some software of the inner shifted square. This image set assesses the accuracy of the DTA element of the gamma algorithm. The geometric image allows the percentage gamma pass rate to be easily determined manually. The image set is depicted in Fig. 1(a) and (b).

Geometric DD test

The 1 mm pixel pitch and 0.25 mm pixel pitch reference images also consist of a geometric square measuring 50 × 50 px and 200 × 200 px respectively. The evaluated images consist of a geometric image of a square in the same position and of identical size, with a dose offset of 1.2%. These image sets

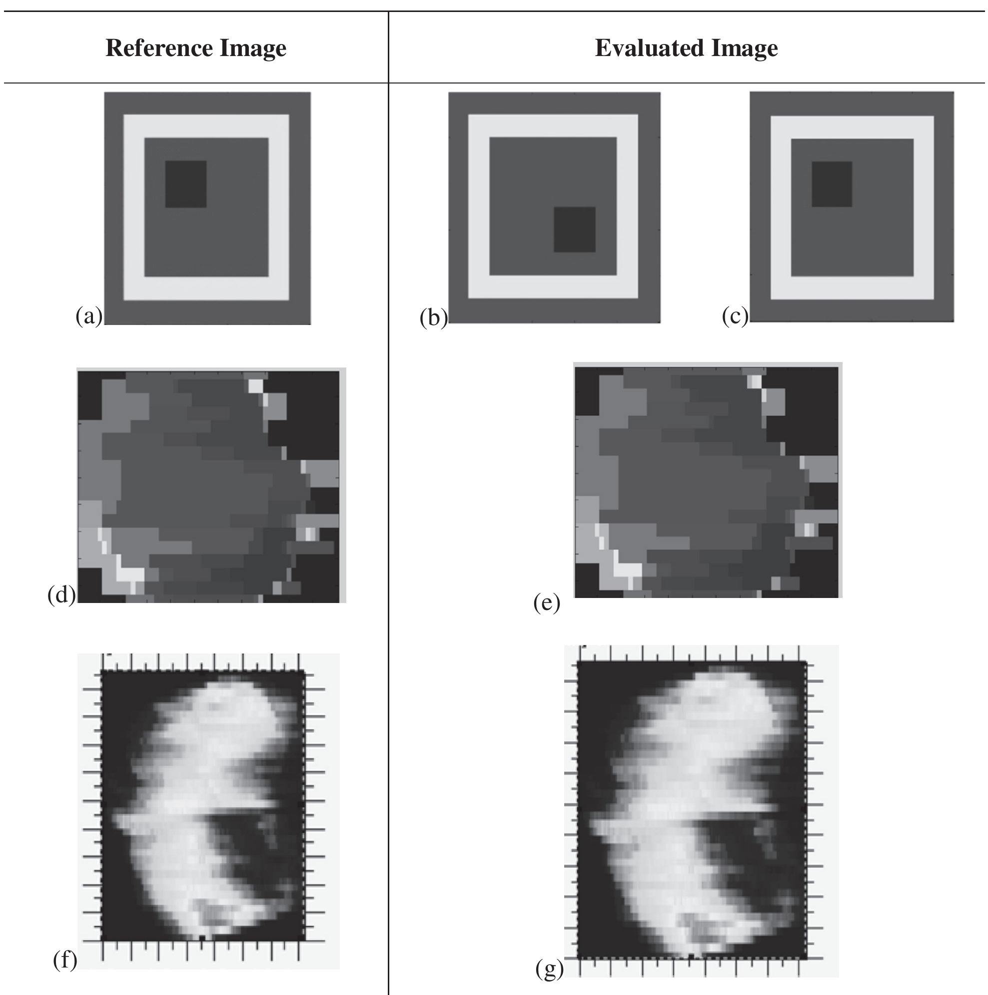

Fig. 1. Reference geometric square (a) with evaluated geometric offset square (b) and evaluated dosimetric offset square (c). Reference (d) and evaluated (e) prostate IMRT field. Reference (f) and evaluated (g) head and neck VMAT arc.

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assess the accuracy of the DD element of the gamma algorithm. The geometric image allows the percentage gamma pass rate to be easily determined manually. The image set is depicted in Fig. 1(a) and (c).

Simple prostate IMRT field

A prostate step and shoot IMRT treatment plan was created using the AAPM TG119 test suite [3]. The field was planned using Oncentra® V3.1 (Nucletron BV, Veenendal, The Netherlands). The reference IMRT field was reconstructed from the multi-leaf collimator (MLC) positions and dose per segment detailed in the Digital Imaging and Communications in Medicine (DICOM) RT plan. The plan was delivered using a Varian 2100CD Clinac (Varian Medical Systems, Palo Alto, CA). The corresponding evaluated IMRT field was reconstructed from the MLC positions and dose per segment detailed in the Varian Dynamic Log files (Varian Medical Systems, Palo Alto, CA) [22]. This image has a modulation complexity score (MCS) [23] of 0.52 and so aims to provide clinically relevant insights into the gamma analysis software when analysing simple treatment fields. The image set is presented in Fig. 1(d) and (e).

Complex head and neck VMAT arc

A complex head and neck VMAT arc was planned using Eclipse (v10.0.28) (Varian Medical Systems, Palo Alto, CA). The reference VMAT arc was reconstructed from the MLC positions and dose per segment detailed in the DICOM RT plan to create a fluence map integrated over the treatment delivery. The plan was delivered using a Varian Truebeam linac (Varian Medical Systems, Palo Alto, CA). The corresponding evaluated VMAT arc was reconstructed from the MLC positions and dose per segment detailed in the Varian Trajectory Log files (Varian Medical Systems, Palo Alto, CA) to create an integrated fluence map of the treatment delivery [24]. This image has a MCS [23] of 0.14 and has the purpose of providing clinically relevant insights into gamma analysis software when analysing complex treatment fields. The image set is presented in Fig. 1(f) and (g).

Image analysis

Manufacturers of the commercially available gamma analysis software listed in Table 2 were invited to take part in this study. Analysis of the 4 image sets was carried out using the software versions also detailed in Table 2.

Table 2
Gamma analysis software invited and participated in the study.

Manufacturer/ distributor	Software	Versions evaluated	Global (G) and/or local (L) analysis
Mobius Med	Doselab Pro	v6.5	G
Open Source	Doselab	v4.11	G
Sun Nuclear	SNC	v6.1, v6.5	G, G & L
OSL	RIT	v6.2	G
OSL	Delta4	v Feb 2013	G
Ashland	FilmProQA	v6.5	G & L
PTW	Verisoft	v5.1, v6.0, v6.1	G & L
iBA	OmniPro	v1.6	G
Varian	Portal Dosimetry	v11.0	G & L
In-house software	Northern Ireland Cancer Centre (NICC)	v3.0	G
In-house software	Christie Hospital Manchester	v1.08	L

To permit analysis by a range of software, all image sets were created in a number of formats including comma delimited, DICOM, tiff, and proprietary formats for OmniPro, Verisoft and Varian Portal Dosimetry. These image formats enabled test images to be imported into all software investigated without errors.

Images were analysed using global dose normalisation, normalised to the maximum dose in each image as detailed in Table 1. Local dose normalisation was evaluated when the option was available in the software as detailed in Table 2. No image alignment was performed. A 3%/3 mm gamma criteria was investigated as this criteria is typically used for assessing clinical treatment deliveries [3], with both global normalisation (3%G3 mm) and local normalisation (3% L3 mm). A 1%/1 mm criteria was also used to identify any subtle differences between gamma algorithm implementations, again for both global and local normalisation denoted as 1% G1 mm and 1%L1 mm respectively. Use of this stringent criteria was possible due to the digital nature of the reconstructed images, removing any uncertainties in detector setup. All analysis was carried out with a minimum dose threshold of 10% of the maximum dose, as typically used in clinical practice [3].

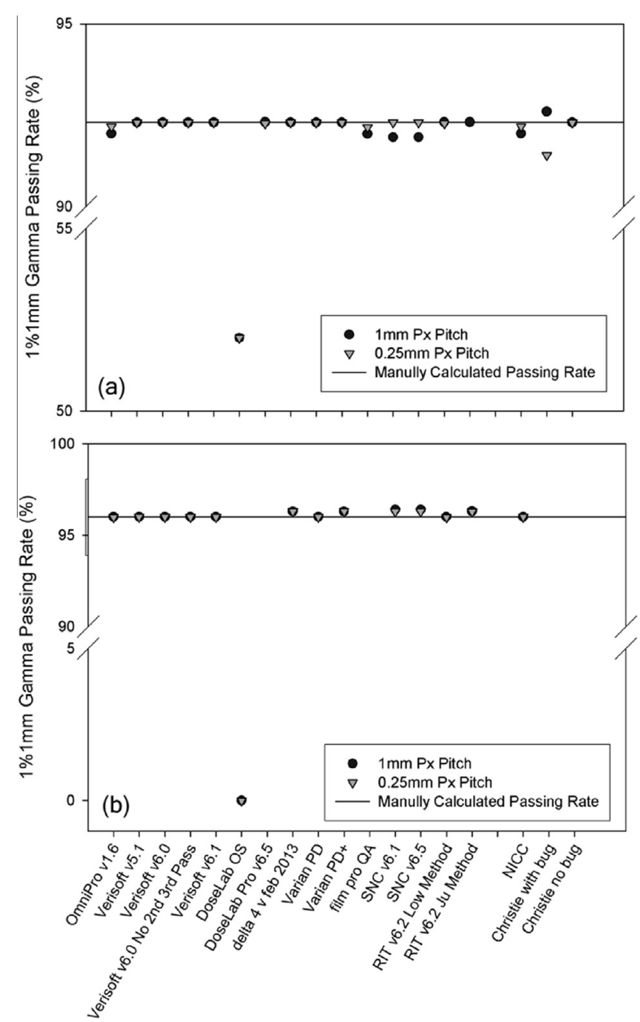

Fig. 2. 1%/1 mm global gamma pass rates for (a) the geometric DTA test and (b) the geometric DD test.

Results

Geometric DTA test

The gamma pass rate for the DTA geometric test can be manually calculated as detailed in Supplementary Table 1, as 92.9% at 3%/3 mm and 92.3% at 1%/1 mm and should be calculated as such by all gamma analysis software. All software investigated did realise this result, as presented in Table 2 and illustrated in Fig. 2(a), with the exception of the open source (OS) DoseLab software, which determined 52.0% of the pixels were within 1%/1 mm and 55.7% were within 3%/3 mm irrespective of the sampling resolution. Inspection of the DoseLab OS gamma pass images suggests only pixels in a square area encompassing the original and shifted square were involved in the analysis, despite setting a 10% lower dose threshold for the analysis. Of note DoseLab Pro, the commercial version of DoseLab software correctly calculated the gamma pass rate. OmniProV1.6, FilmPro QA and NICC gamma algorithm calculated the gamma pass rate at 3%G3 mm to be 92.6% with 1 mm pixel pitch and 92.8% with 0.25 mm pixel pitch. At 1% G1 mm, OmniProV1.6, FilmPro QA and NICC again achieved lower than expected results with 92.2% pass rate at 0.25 mm pixel pitch. These subtle differences can result from a search for gamma values $\leqslant$1 rather than <1. The in-house Christie software was modified to accept the image format of this test suite. This modification introduced a bug into the software, which was identified through analysis of these test images and thus could be rectified.

Geometric DD test

The gamma pass rate for the DD geometric square can be determined manually as detailed in Supplementary Table 1 as 100% at 3%/3 mm and 96.0% at 1%/1 mm and should be calculated as such by all gamma analysis software. Again all software, with the exception of DoseLab OS, approximated to this result with some subtle variations. A number of algorithms, Delta4, Varian PD+, SNC and RIT (Ju method) increased the result at 1%/1 mm to 96.3%. This could be due to pre-processing of the data, such as interpolation of the reference dose distribution or resampling of the data provided. DoseLab OS found 0% pixels passed the DD tests. Inspection of the gamma pass image suggests only pixels in the inner offset square were involved in the analysis, despite setting a 10% lower dose threshold for the analysis. Again, the commercial version of this software, DoseLab Pro, correctly calculated the gamma pass rate.

Simple prostate IMRT field

The median and inter quartile range (IQR) gamma pass rate for the IMRT field at 3%/3 mm was 100.0(99.8–100.0)% and 100.0 (100.0–100.0)% [Median (IQR)] with 1 mm and 0.25 mm pixel pitch respectively. The median gamma pass rate for the IMRT field at 1%/1 mm was 99.3(98.5–99.6)% and 99.6(99.0–99.9)% [Median (IQR)] with 1 mm and 0.25 mm pixel pitch respectively. Results for each software are presented in Fig. 3(a) for 3%G3 mm and Fig.3(b) for 1%G1 mm and are tabulated in Supplementary Table 2. A sample gamma pass map of the 1 mm pixel pitch and 0.25 mm pixel pitch prostate IMRT field is presented in Supplementary Fig. 1. At 3%G3 mm and 1 mm pixel pitch, 1% variation exists between the pass results from gamma software implementations. At 3%G3 mm increased image resolution to 0.25 mm pixel pitch increased the gamma pass rates and reduced the variation between software implementations to 0.5%. Conversely, improved resolution reduced the gamma pass rate in Verisoft V5.1 but not in Verisoft V6.0. This is due to Verisoft resampling of the reference data to 0.5 mm in V5.1 but in V6.0 only resampling the reference data

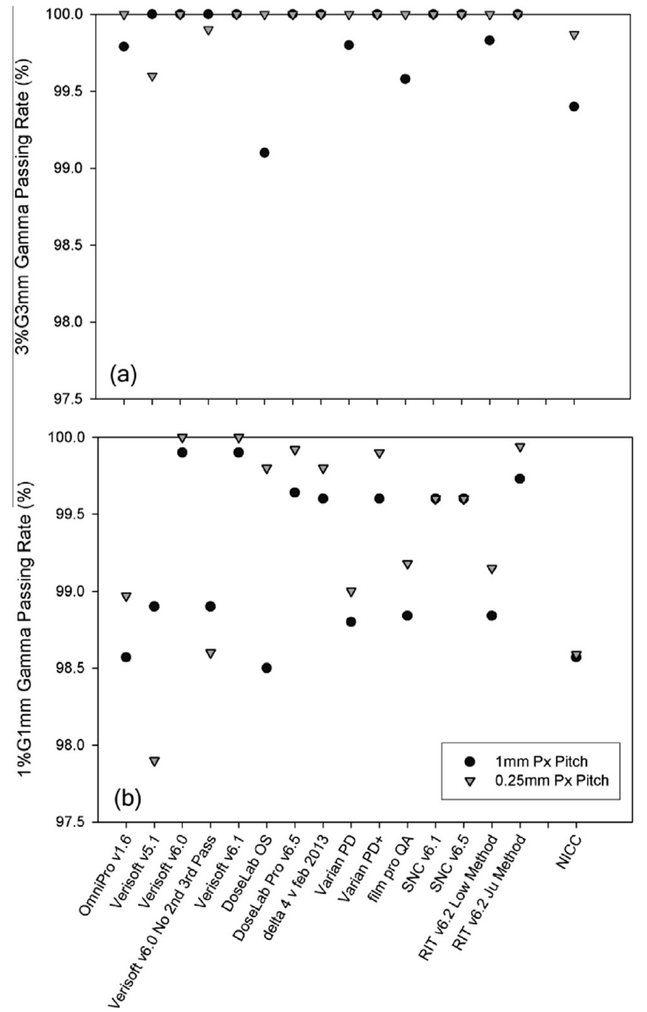

Fig. 3. Global gamma pass rates for the IMRT field at (a) 3%/3 mm and (b) 1%/1 mm.

to 0.5 mm if the original sampling is >0.5 mm. SNC V6.1 and SNC V6.5 calculated no variation in the gamma pass rate for either 0.25 mm or 1 mm pixel pitch. This is because both SNC V6.1 and V6.5 automatically resampled all data to 1 mm pixel resolution, prior to analysis.

Similar trends were noted in results for local gamma analysis, as illustrated in Supplementary Fig. 2 and detailed in Supplementary Table 2, with a variation in gamma pass rates of 0.5% at 3%L3 mm and >10% at 1%L1 mm.

Complex head and neck VMAT arc

For the VMAT arc, the median and IQR gamma pass rate at 3%/3 mm was 99.9(99.8–100.0)% and 100.0(100.0–100.0)% with 1 mm and 0.25 mm pixel pitch respectively and at 1%/1 mm was 97.7(94.4–98.2)% and 98.9(98.7–99.4)% again for 1 mm and 0.25 mm pixel pitch respectively. The individual results from analysis of the complex VMAT arc by each software are presented in Fig. 4(a) at 3%G3 mm and Fig. 4(b) at 1%G1 mm and tabulated in Supplementary Table 2. At 3%G3 mm and 1 mm pixel pitch, <0.5% variation exists between the pass results between gamma software implementations. At 3%/3 mm increased image resolution to 0.25 mm pixel pitch improved the gamma pass rates and reduced the variation between software to <0.2%. However at 1%G1 mm, analysis of inappropriately sampled 1 mm pixel pitch images

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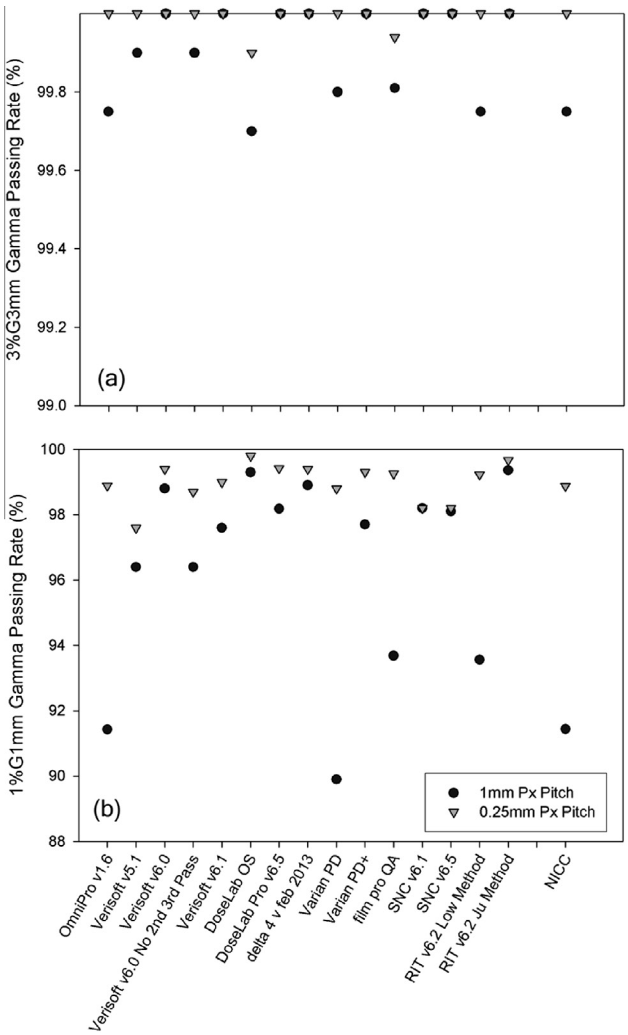

Fig. 4. Global gamma pass rates for the VMAT arc at (a) 3%/3 mm and (b) 1%/1 mm.

increased the variation between gamma pass rates to >10%, revealing the sensitivity of some implementations of gamma to errors at steep dose gradients found in the complex VMAT arc image set. Such errors were minimised in analysis of the 0.25 mm sampled pixels, where the variation between software implementations reduced to <3%.

Results for local gamma analysis follow similar trends to global analysis as shown in Supplementary Fig. 3 and Table 3, with variation at 3%L3 mm of <2%. The variation in pass results increased at 1%L1 mm when analysing appropriately sampled images to >10% and inappropriately sampled images to >15%.

Discussion

Variation between gamma pass rates exists between commercially available gamma analysis software. Although all software versions investigated could accurately calculate the DTA and DD element of the gamma algorithm as tested with a simple geometric shape, a simple IMRT field and a complex VMAT arc revealed differences between the implementations of gamma software that increased with stricter gamma criteria, a reduction in image resolution, an increase in plan complexity and moving from global to local criteria.

The DICOM and proprietary formats enabled all test images to be easily imported into all software without errors. The independent tests of the DTA and DD validated that variations between software versions are not a consequence of errors in the algorithms but subtle differences in the implementation itself. The digital nature of the images analysed in this study removed compounding factors such as delivery fluctuations, detector geometry, detector resolution and set up errors from the analysis and enabled direct comparison of gamma algorithm implementations and quantification of the level of variability that can be expected therein. For example, in RIT software the Ju method [14] increased the gamma passing rate compared to the Low method [1], illustrating the effect of gamma algorithms on passing rates. Such data may be utilised when comparing local or multi-centre results to results reported in the literature.

Published data has demonstrated the relationship of gamma pass rates with image resolution [18]. The effect of image resolution and software pre-processing has also been demonstrated in this study. Removing uncertainties in setup errors permitted the use of the stringent 1%/1 mm gamma criteria. 1%/1 mm gamma analysis results clearly demonstrate the impact of failing to comply with sampling criteria of pixel pitch $\leqslant \frac{\text{DTA Distance}}{3}$ for some implementations of the gamma algorithm [25].

Recent literature has presented compelling evidence for moving toward tighter gamma criteria and local gamma analysis [26]. However, as highlighted by this study and others [18], tighter gamma criteria results in greater variation between gamma pass rates from vendors and thus confidence intervals for gamma pass rates may need to be specific for vendor and software version. Additionally, this study has shown for local gamma analysis variation in gamma pass rate of greater than 1.5% exists between vendors and software versions at 3%L3 mm and increase to over 10% when using the stricter criteria of 1%L1 mm. This large variation may be a consequence of the digital nature of the image sets, with broad areas of constant dose. However, these results demonstrate the need for each institution to fully commission and assess the gamma algorithm being implemented as well as the need for vendor and software versions to be reported in the literature. A further limitation of this study is the 2D nature of the suite of image sets. However, although a number of vendors provide a 3D gamma analysis, generally, the 3D data is effectively resampled into 2D planes [18].

This study provides data on the variation that can exist in gamma pass rates from different implementations of the gamma algorithm between various manufacturers and software versions. With such software being used to inform clinical decisions, the test suite provided in this study enables institutions to validate gamma analysis software, interpret the sensitivity and limitations of the gamma software and incorporate such software into a quality assurance program.

Conflict of interest

None.

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Appendix A. Appendix

Inventory of supplementary test image files.

Test image	Px. pitch (mm)	Evaluated image	Reference image
DTA test	1.0	GeometricSquare_Evaluated_1mmPx_DTA_Test	GeometricSqaure_Reference_1mmPx
DTA test	0.25	GeometricSquare_Evaluated_0_25mmPx_DTA_Test	GeometricSqaure_Reference_0_25mmPx
DD test	1.0	GeometricSquare_Evaluated_1mmPx_DD_Test	GeometricSqaure_Reference_1mmPx
DD test	0.25	GeometricSquare_Evaluated_0_25mmPx_DD_Test	GeometricSqaure_Reference_0_25mmPx
IMRT field	1.0	ProstateIMRT_Evaluated_1mmPx	ProstateIMRT_Reference_1mmPx
IMRT field	0.25	ProstateIMRT_Evaluated_0_25mmPx	ProstateIMRT_Reference_0_25mmPx
VMAT arc	1.0	H&N_VMAT_ Evaluated _1mmPx	H&N_VMAT_Reference_1mmPx
VMAT arc	0.25	H&N_VMAT_ Evaluated _0_25mmPx	H&N_VMAT_Reference_0_25mmPx

Inventory of supplementary test image formats.

Format	Description
.csv	Comma delimited text file
.dcm	DICOM format
.tiff	TIFF image format
.dat	Proprietary format for Verisoft Software
.dxf	Proprietary format for Varian Portal Dosimetry
.opg	Proprietary format for OmniPro Software

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.radonc.2015.11.034.

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