Study on the ability of the three-dose-volume-histogram-gamma (3DVH-γ) analysis and bio-mathematical model in detecting dose changes caused by dose-calculation-grid-size (DCGS)

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Abstract

Objective : To explore the efficacy and sensitivity of 3DVH-γanalysis and bio-mathematical model for cervical cancer in detecting dose changes caused by dose-calculation-grid-size(DCGS).

Methods： 17 patients' plans for cervical cancer were enrolled，Pinnacle TPS，VMAT，, and the DCGS was changed from 2.0mm to 5.0mm to calculate the planned dose respectively. The dose distribution calculated by DCGS = 2.0mm as the " reference " data set (RDS) , the dose distribution calculated by the rest DCGS as the"measurement"data set (MDS), the 3DVH-γ passing rates and the (N)TCPs of the all structures under different DCGS were obtained , and then analyze the ability of 3DVH-γ analysis and (N)TCP model in detecting dose changes and what factors affect this ability.

Results: The effect of DCGS on planned dose was obvious. When the γ-standard was 1.0mm, 1.0% and 10.0%, the difference of the results of the DCGS on dose-effect could be detected by 3DVH-γ analysis (p s<0.05). With the decline of the standard, 3DVH-γ analysis' ability to detect this difference shows weaker. When the standard was 1.0mm, 3.0% and 10.0%, the p value of >0.05 accounted for the majority. With DCGS=2.0mm being RDS, Δγ-passing-rate presented the same trend with Δ(N)TCPs of all structures except for the femurs only when the 1.0mm, 1.0% and 10.0% standards were adopted for the 3DVH-γ analysis.

Conclusions: The 3DVH-γ analysis and bio-mathematical model can be used to analyze the effect of DCGS on the planned dose. For comparison, the former's detection ability has a lot to do with the designed standard, and the latter's capability is related to the parameters and calculated accuracy instrinsically.

Introduction

The dose calculation grid size (DCGS) is a basic parameter setting in the design of the plan.Usually, a commercial treatment planning system (TPS) will provide various DCGS within a certain range for designers to choose for different needs.For example, the commercial Pinnacle TPS provides DCGS ranging from 1.0mm to 10.0mm,and the default DCGS is 4.0mm.Larger DCGS is commonly adopted for calculation in cases with larger target volumes and organ-at-risk (OAR) volumes for better calculation efficiency. However, a smaller DCGS should be chosen for dose calculation in radiotherapy for head and neck tumors to obtain precise doses of small-volume OARs including lens, optic nerveand pituitary, etc.,especially important for OARs with strict maximumdose limit[1,2].

The difference in doses caused by different grid sizes may affect the evaluation of the quality of physical solutions, although the DCGS can not cause the actual absorbed dose when the accelerator's parameters are certain. (This is why the planned dose values and (N)TCP values calculated under different DCGS are all called "calculated" values in the following sections). Therefore, it is a crucial task to understand the effect of DCGS on the physical and biological doses in radiotherapy for cervical cancer (CC). γ analysis is currently the most common and generally accepted method for quantitatively assessing the difference

between the two dose-distributions (DDs)[3,4]. It detects the difference between the two DDs bya designed γstandard(e.g. 3.0mm, 3.0%, 10%)and it will provide a report on passing rate[5,6]. The standard of 3.0mm, 3.0% and 10% is the most widely used, in which 3.0mm refers to the consistency of distance, 3.0% refers to the maximum allowable dose difference, and 10% is the threshold and when the dose is less than 10% of the reference dose, which does not participate in Gamma analysis. Selecting 10% is widely recommended[7,8].In intensity modulated radiation therapy (IMRT),γ analysis is usually used to analyze the difference between the TPS-outputed and the actually measured dose distribution to evaluate the degree of dose deviation caused by various reasons during the execution of the plan, further to determine whether a plan is to execute based on the evaluation.However, previous studies have shown that different dose QA systems have different abilities to detect errors based on the dose distribution output by TPS.Hussein et al.[9]enrolled pelvis and head & neck IMRT and RapidArc™ plans, and compared the differences in the detecting dose error of five commercial products:PTW Verisoft, Delta4 software, SNC Patient, Varian Portal Dosimetry and IBA OmniPro.The results showed that for the same pass-rate criteria, different devices and software combinations exhibited varying levels of agreement with the predictedγanalysis.On the other hand, different gamma analysis standards will get different passing rates. Research by Heilemann et al.[10]showed that the 3.0mm, 3.0%, and 10.0% standards were not sufficient to detect the deviation caused by the MLC position uncertainty, and this standard, at least, has to be 2.0mm, 2.0%, 10.0%.

The focus on the variation of planned dose (PD) is due to the fact that it could cause changes in the biological effects. Specifically, in the clinical practice of radiotherapy, the alteration in physical dose will bring about changes in tumor control probability (TCP) and nomal tissue complication probability (NTCP). Therefore, the current project, under the condition of DCGS changes, used the dose distribution calculated by DCGS=2.0mm as the reference data set (RDS) to explore the efficacy and sensitivity of the 3DVH-γ analysis and the bio-mathematical model on dose change detectionby analyzing the 3DVH-γ passing rates of all structures and the relationship between γ passing rate and (N)TCP.

Materials And Methods

1.1 Patient meterials

A retrospective study was performed on the physical plan of 17 patients with CC who were treated in the Department of Radiation Therapy of our hospital from December 2017 to November 2018. And the 17 patients' plans were intially designed and evaluated with DCGS=4.0mm. The patient's PGTV volume was 20.0-395.0 cm^3, and the PTV volume was 880.0-2587.0 cm^3. The average volumes of the two target volume were 128.9±110.2cm^3, 1752.9±460.1cm^3, respectively.The rectum's mean volume was 59.3±25.4cm^3, and the bladder's was 257.5±165.6cm,and the L-femur' s and R-femur's were 107.2±19.1cm^3, 108.2±19.6cm^3.These patients were in a supine position with both hands surrounding his head, and the patient was fixed with a thermoplastic mesh. The Siemens Somatom Sensation Open 24 CT (Siemens Co., Munich, Germany) was used as the data acquisition system. The range of scanning

was from the head of the diaphragm to lower 1.0cm of the bottom pubic symphysis. And the CT data of each patient was reconstructed with a 3.0 mm layer thickness, was transmitted to Pinnacle TPS 9.10.

1.2 Design of VMAT radiotherapy plan

17 patients were treated with a Versa HD linear accelerator (Elekta Medical Systems Co., Stockholm, Sweden) of 6 MV photon beams.The volumetric modulated arc therapy (VMAT) plan of a 360^{o} full bow with 2 arcs was designed for every patient based on Smart Arc inverse optimization.The objective functions were shown inTable 1.The doses were calculated with the Collapsed Cone Convolution (CCC) algorithm. The CCC dose engine determines dose deposition by a three-dimensional convolution/superposition of the Total Energy Released per unit Mass (TERMA) with a dose spread function. The TERMA is determined by projection of the beam energy fluence through the patient CT volume. The effects of changes in tissue composition on dose distribution are approximated by scaling the dose spread function by the radiological distance to account for the presence of heterogeneities with respect to scattered radiation. The superposition of the calculated dose distribution from all TERMA volumes determines the final 3D dose distribution in patient[11]. The planning prescription setting was as follows: the planning target volume (PTV) prescription being 45.0-50.0Gy / 25F, and the planning volume of the gross tumor (PGTV) prescription being 60.0-62.5Gy / 25F.

All VMAT physical schemes were designed with Pinnacle TPS (version 9.10). When the default value was DCGS = 4.0mm, the planners optimized and adjusted the treatment plans for CC patients based on their own previous experience . After all the indicators of the plans met the clinical requirements, changed the DCGS (from 2.0mm to 5.0mm) and recalculated dose in the target volumes and OARs.

1.3 3DVH-γstandard and passing rate

After the emergence of IMRT technology, verification of radiation dose before the implementation of treatment has become a very important part of the radiotherapy process.Dose verification can be divided into point dosimetry verification, plane dosimetry verification and gel dosimetry verification.The point dosimetry verificationandGel dosimetry verification[12,13] have not been widely accepted because of various reasons, and the plane dosimetry verification has become a popular method. The commercially available PTW-ARRAYs[14]and IAB-ARRAYs[15]are the most popular tools for plane dose verification. These ARRAYsonly respond correctly to beams perpendicular to their matrix plane, and it is necessary to combine the scattered beams into one direction when using these ARRAYs. This feature makes these ARRAYs less suitable for dose verification of VMAT with rotating beams. So, Delta 4, ArcCheck and Octavius 4D for dose verification of VMAT are more common in daily work [16-18].

Although the toolsadvanced, there has been no fundamental change in analytical methods. The γ analysis has been used throughout IMRT dose verification.The commonly recommendedγ analysis standards are 3.0mm, 3.0%, and 10% threshold[7,8], but studies have shown that, depending on the technology and the disease, we should adopt stricter standards or other supplement analysis to analyze errors[19,20].

The3DVH-gamma analysis is also a standard gamma-analysis.The 3DVH-gamma-analysis is that during the dose of reconstruction before the analysis of gamma-analysis, the software will be used the planned dosed Perturbation (PDP) algorithm corresponding the hardware. For example, if the hardware is ArcCHECK, the corresponding algorithm is ArcCHECK-planned-dosed- perturbation (AC-PDP). AC-PDP is the engine behind 3DVH when used in conjunction with ArcCHECK 4D measured dose to generate quality assurance (QA) metrics based on patient dose and DVH. At the core of AC-PDP is true 4D Measurement Guided Dosed Reconstruction (MGDR), which generates a high-density, High-resolution 3D dose estimate using the ArcCHECK dose movie data which has time resolved to 50 msec and an integrated virtual inclinometer (VI) [21].

This article was to investigateerrors amongplanned dose caused by DCGS with dose distribution calculated by DCGS=2.0mm as RDS andthe dose distribution calculated byDCGS=3.0mm, 4.0mm, 5.0mm as MDS, respectively.And we thought the locationuncertainty was scarcely influential element under the situation.Therefore, when setting the γ analysis standard, we setted the following 3 standards: 1.0mm, 1.0%, 10% threshold; 1.0mm, 2.0%, 10% threshold; 1.0mm, 3.0% , 10% threshold.

1.4 TCP and NTCP calculation

The link between physical dose (change) and biological effect (change) has always been our focus. Changes in DCGS will certainly bring about changes in the physical dose, as well as the biological effects. It is well known that changes in biological effects have more direct clinical significance, so this study ignored the physical dose and directly calculated the changes in biological effects caused by changes in DCGS by using biological model.

Some biologically related models for plan optimization and/or evaluation have been introduced into treatment planning tools for clinical use.A variety of dose- response models with a series of organ-specific model parameters were reported in the literatures, and were widely accepted as follows[22,23]:

[Please see the supplementary files section to view the equations.]1

(2.1)

(2.2)

(2.3)

(2.4)

Where, a is an organ-specific constant, and its corresponding value is in the literatures[24,25]. $v_i$is the fractional volume of the organ receiving D_i. m and n are unique organ-specific constants[24,25].TD_{50} is an uniform dose that is absorbed dose at a 50% complication probability, and TCD50 is an uniform dose that is absorbed dose at a 50% control probability.

1.5 Statistical analysis

Origin 8.0 was used for drawing and SPSS 20.0 was used for statistical analysis.*Paired t test* was used for statistical analysis, and $p>0.05$ indicates no significant difference, and $0.01<p<0.05$ indicates significant difference, and $p<0.01$ indicates very significant difference.

Results

2.1 (N)TCP and absolute dose (AD)changes with DCGS

DCGS'schange indicated the change of "collection-dose-unit". Key dose points on DVH of each structure with DCGS'schangewere counted and analysed. As we all know, for target, minimum dose (MinD), maximum dose (MaxD) and mean dose (MeanD)were important for efficacy[26]. And for organ-at-risk, MeanD was important for toxicity[27]. So, We counted on PGTV's MinD, MaxD and MeanD, and PTV's MinD and MeanD (because PGTV is included in PTV, the maximum dose in PTV is located in PGTV), and MeanD of Bladder, Rectum and Femurs (shown in Fig 1- Fig 4).

The 68differentialDVHsof 17 patients' radiotherapy plans (17*4=68) were exported as .txt data files. The data in the .txt file were read by MATLAB program and put into formulas (1) and (2.4) to calculate the EUD of each OAR and each target. Then TCP and NTCP were calculated using the formulas (1) and (2.1). Figures drawn by Origin8.0 software were shown inFig 5.andFig 6. As shown in the figures,the influence of DCGS on the calculated value of (N) TCP was obvious,and the calculated value of (N) TCP decreased with the increase of DCGS.

Fig 1. Display of MinD, MaxD and MeanD of PGTV change casused by DCGS

Fig 2. Display of MinD and MeanD of PTV change casused by DCGS

Fig 3. Display of MeanDs of Rectum and Bladder change casused by DCGS

Fig 4. Display of MeanDs of R-Femur and L-Femur change casused by DCGS

Fig 5. Display of TCP change casused by DCGS

Fig 6. Display of NTCP change casused by DCGS

2.2 *p*-value analysis

The change of DCGS would bring about the change of each structure's absorption dose. In order to quantify the DC,we selected γ analysis to analyze the differencebetween the dose corresponding to DCGS=2.0mm acting as RDS and the dose corresponding to DCGS=3.0mm, 4.0mm, 5.0mm acting as MDS, respectively.

In order to reflect the statistical significance of the dose difference caused by different DCGS, we grouped and named the results of γ analysis, as shown inTable 2. For example, when the γ analysis standard setting was 1.0mm, 1.0%, 10.0% and the dose distributions of DCGS=3.0mm and DCGS=2.0mm were compared,the results were grouped as Aa. And the paired *t*-test results of each structure were shown inFig. 7. Theγ-standard had a significant impact on the *γ*-analysis' sensitivity. When the γ-standard was 1.0mm, 1.0% and 10.0%,the difference of the results of the DCGS on dose-effect could be detected by 3DVH-γ analysis (*p*s<0.05). With the decline of the standard, 3DVH-γ analysis' ability to detect this difference was also declining. When the standard was 1.0mm, 3.0% and 10.0%,the *p* value of >0.05 accounted for the majority.It was a high probability event that the dose difference between DCGS=0.5mm and DCGS=3.0mm (or the other two DCGSs) could not be detected by this analysis.

Fig 7. The map of every structure's paired t test under varied γ analysis standard.

2.3 Correlation of △ (N)TCP and △ γ

The (N)TCPs' and γ values both changed with DCGS. To explore whether there was a certain correlation between these two changes, we investigated △(N)TCP and △γ separately.△(N)TCP was defined as the (N)TCP value when DCGS=2.0mm minus the (N)TCP value when DCGS was the other value. △γ was defined as 100.0% minus the γ passing rate when the dose of DCGS=3.0mm, or 4.0mm, or 5.0mm compared that of DCGS=2.0mm.Because *γ* analysis was carried out with three different standards in this paper,the △γ were divided into △γ1, △ γ2 and △γ3corresponding to 1.0mm, 1.0%, 10.0%; 1.0mm, 2.0%, 10.0% and 1.0mm, 3.0%, 10.0%.

In order to simplify the following writing, we describe the corresponding relationship as follows.

"M" corresponding to △ (N)TCP =□N□TCP(DCGS=2.0mm) -□N□TCP(DCGS=3.0mm) and

△ γ=100.0% - γ passing rate when DCGS=3.0mm compared DCGS=2.0mm.

"N"corresponding to △ (N)TCP=□N□TCP(DCGS=2.0mm) -□N□TCP(DCGS=4.0mm) and

△ γ=100.0% - γ passing rate when DCGS=4.0mm compared DCGS=2.0mm.

"L"corresponding to △ (N)TCP=□N□TCP(DCGS=2.0mm) -□N□TCP(DCGS=5.0mm) and

△ γ=100.0% - γ passing rate when DCGS=5.0mm compared DCGS=2.0mm.

The △ (N)TCP and △γ were shown in Table 3 , Table 4 and Table 5. As shown in the tables, when the calculated values of (N)TCP of the targets, the bladder and the rectum decreased with DCGS increasing, the γ passing rate also decreased when the standard was 1.0mm, 1.0%, 10.0%.

Discussion And Conclusion

Compared with conformal radiotherapy, intensity-modulated radiotherapy can improve the conformal degree of the target area, reduce the dose of organs at risk, and reduce the acute and late toxicity of organs[28,29]. VMAT is a higher form of modulated radiation therapy, VMAT and IMRT have been compared in many studies[30,31]. The publications relating to planning[32] , commissioning[33], QA [34]and clinical implementation[35]have been published, which made VMAT technology spread quikly around the world. VMAT technology is widely used for the CC radiotherapy. These studies on the application have shown that VMAT technology can be used for cervical cancer radiotherapy, and compared with High Dose Rate brachytherapy, VMAT plan achieves significant dose reduction of rectum, bladder and sigmoid, as well as superior homogeneous target coverage compared to brachytherapy plan[36-38]. Therefore, the CCs' VMAT plans were selected as the research object in this study.Gantry rotation speed and dose rate vary when a VMAT schedule is excuted, which made the complexity of VMAT QA be more than that of IMRT[39]. As the origins of QA failure could be uneasy to confirm this failure caused by dose calculation from TPS, or dose delivery from linac, or detectors of phatom, or other aspects. Therefore, the source of the (N)TCP and γ passing rate was fixed on one factor DCGS.

It is an important basis for us to set up DCGS in the planning design to consider the efficiency of calculation under the precise of satisfying the accuracy of dose calculation. Many studies from radiation oncology deparments recommend DCGS=2.0mm be for the clinical requirements[40,41]. This conclusion was the main reason why in this paper we chose DCGS=2.0mm as the research basis. Secondly, the low computational efficiency of DCGS=1.0mm makes it difficult in clinical practice, when was DCGS=1.0mm, the Pinnacle TPS would spend about two 2.0 hours to calculate once a dose distribution for a patient.

Gamma analysis is a commonly used method to compare differences between two dose distributions, but the ability of gamma analysis to detect errors is closely related to the criteria set.Fig. 7of the "***p*-value analysis**" in this paper showed that when 1.0mm, 1.0% and 10.0% was used as the standard in the γ analysis,there was a statistical difference (*p*s<0.05) between any two results of γ analysis when DGCS was 3.0mm, 4.0mm or 5.0mm*vs* 2.0mm, indicating that the Gamma analysis was sensitive to changes of DCGS.However, when 1.0mm, 3.0% and 10.0% was used as the standard in γ analysis, there was mostly no significant difference (*p*s>0.05)between any two results of γ analysis when DGCS was 3.0mm, 4.0mm or 5.0mm*vs* 2.0mm, and at this time the Gamma analysis was not sensitive to changes of DCGS.Many studies' results all reflected the similar conclusion of γ-standard and γ analysis'sensitivity[42,43]. The difference was that these studies had set change of the standard in two dimensions (distance and dose) at the same time, for example,change the $\gamma_{3.0\%\text{-}3.0mm}$ to $\gamma_{2.0\%\text{-}2.0mm}$. When the dose standard of γ analysis was relaxed from 1.0% to 3.0%, the "dose points" of 1.0% < dose error <3.0%that failed with the standard of 1.0mm, 1.0% and 10.0% were allowed to pass, so the ability of γ analysis to detect dose error ϵ [1.0%, 3.0%]was lossing. At the same time, we could also get from the results that the majority of the dose "calculated value" changes as DCGS from 2.0mm to 5.0mm were<3.0%.

However,the situation was different when the (N)TCP biological mathematical model was used to detect these dose changes, and theoretically any DS caused by DCGScould be represented in the value of (N) TCP as long as the value of (N) TCP was accurate enough.So, when we changed DCGS we got the trend of (N) TCP and Δ (N) TCP, even though Δ (N) TCP was not a big value. In the study, Δ NTCP of the Femurs was always 0.00 in Table 5. It was not because NTCP did not change, but because the value was omitted because of too small, which was cause by parameters' value of NTCP model.

The TCP and NTCP were expected to be obtained by studying the targets' and OARs' physical dose, because the two formers were of greater clinical significance. So this paper studied the relationship between Δ(N)TCP and Δγ. With the DCGS becoming larger, the relatively-lower-dose in the normal tissues located around the target was more calculated into the target, so the overall dose of the target decreased and the TCP decreased. The focused irradiation mode of radiotherapy determines the general trend of dose decrease from the target area to the periphery, with the highest dose in the target. In this paper, we investigated the OARs, bladder, rectum, and femurs were the organs of adjacent to the targets, as the DCGS became larger, their relatively-high-dose was "deprived" by the targets, and the dose "deprived" by them from their surrounding was relatively-high-dose, so the DCGS became larger, their overall doses were falling, and their NTCPs were falling.

The 3DVH-γ analysis and bio-mathematical model can be used to analyze the effect of DCGS on the planned dose,and the former's detection ability has a lot to do with the designed standard,and the latter's capabilityis related tothe parameters and calculated accuracy of the latter.

Abbreviations

DCGS dose calculation grid size;

PD planned dose

DVH dose-volume histogram;

RDS reference data set

MDS measurement data set

TCP tumor control probability

NTCP normal tissue complication probability

TPS treatment planning system

OAR organ-at-risk

CC cervical cancer

DD dose distribution

IMRT intensity modulated radiation therapy

VMRT volumetric modulated arc therapy

PTV planning target volume

PGTV planning gross tumor volume

Declarations

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Authors' contributions

HB conducted all digital analyses and performed thestatistical analysis. HB and XRW made substantial contributions to theconception and design of the work. HB, SJZ and XHL were majorcontributors in drafting and writing the manuscript. FHC, JWY, SJZ werereresponsible for radiation treatment planning. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analysed during the current study are not

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are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors agreed to publish this paper in Radiation Oncology

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1 Dose-volume criteria used in the cervix cancer VMAT plans

Volume of interest	Dose-volume criteria (cGy)
PGTV	MinD=95%PD, V_{PD}≥95%, MaxD=107%PD
PTV	MinD=95%PD, V_{PD}≥95%, MaxD=107%PD
Rectum	V40<60%, $D_{33\%}$<45Gy
Bladder	V40<40%, $D_{33\%}$<45Gy
L-Femur	V45<5%, V30<30%
R-Femur	V45<5%, V30<30%
Intestine	V30<30%
Cord	MaxD=45Gy

Note: PD is the prescribed dose

Table 2 The group and name of γ analysis results

DCGS	γ-Cri	1.0mm, 1.0%, 10.0%	1.0mm, 2.0%, 10.0%	1.0mm, 3.0%, 10.0%
3.0mm	*vs* 2.0mm	Aa	Ab	Ac
4.0mm	*vs* 2.0mm	Ba	Bb	Bc
5.0mm	vs 2.0mm	Ca	Cb	Cc

Table 3. Display of △TCP and △γ

Name	*PGTV*				*PTV*			
	△TCP	*△γ1*	*△γ2*	*△γ3*	*△TCP*	*△γ1*	*△γ2*	*△γ3*
M	0.40	*0.20*	*0.00*	*0.00*	*0.40*	*0.86*	*0.27*	*0.00*
N	*0.90*	*1.63*	*0.20*	*0.00*	*0.70*	*1.47*	*0.61*	*0.00*
L	*1.40*	*10.61*	*0.71*	*0.00*	*1.10*	*6.75*	*1.66*	*0.48*

Table 4. Display of △NTCP and △γ for the bladder and the rectum

Name	*Bladder*				*Rectum*			
	△NTCP	*△γ1*	*△γ2*	*△γ3*	*△NTCP*	*△γ1*	*△γ2*	*△γ3*
M	0.20	*0.50*	*0.12*	*0.00*	*0.30*	*0.08*	*0.16*	*0.03*
N	*0.40*	*1.54*	*0.69*	*0.37*	*0.60*	*2.15*	*0.40*	*0.40*
L	*0.50*	*4.58*	*1.22*	*0.33*	*0.90*	*2.99*	*1.42*	*0.00*

Table 5. Display of △NTCP and △γ for the femurs

Name	*L-Femur*				*R-Femur*			
	△NTCP	*△γ1*	*△γ2*	*△γ3*	*△NTCP*	*△γ1*	*△γ2*	*△γ3*
M	0.00	*0.02*	*0.00*	*0.00*	*0.00*	*0.17*	*0.00*	*0.00*
N	*0.00*	*1.07*	*0.19*	*0.01*	*0.00*	*0.75*	*0.02*	*0.00*
L	*0.00*	*2.93*	*0.60*	*0.08*	*0.00*	*1.70*	*0.33*	*0.00*

Figures

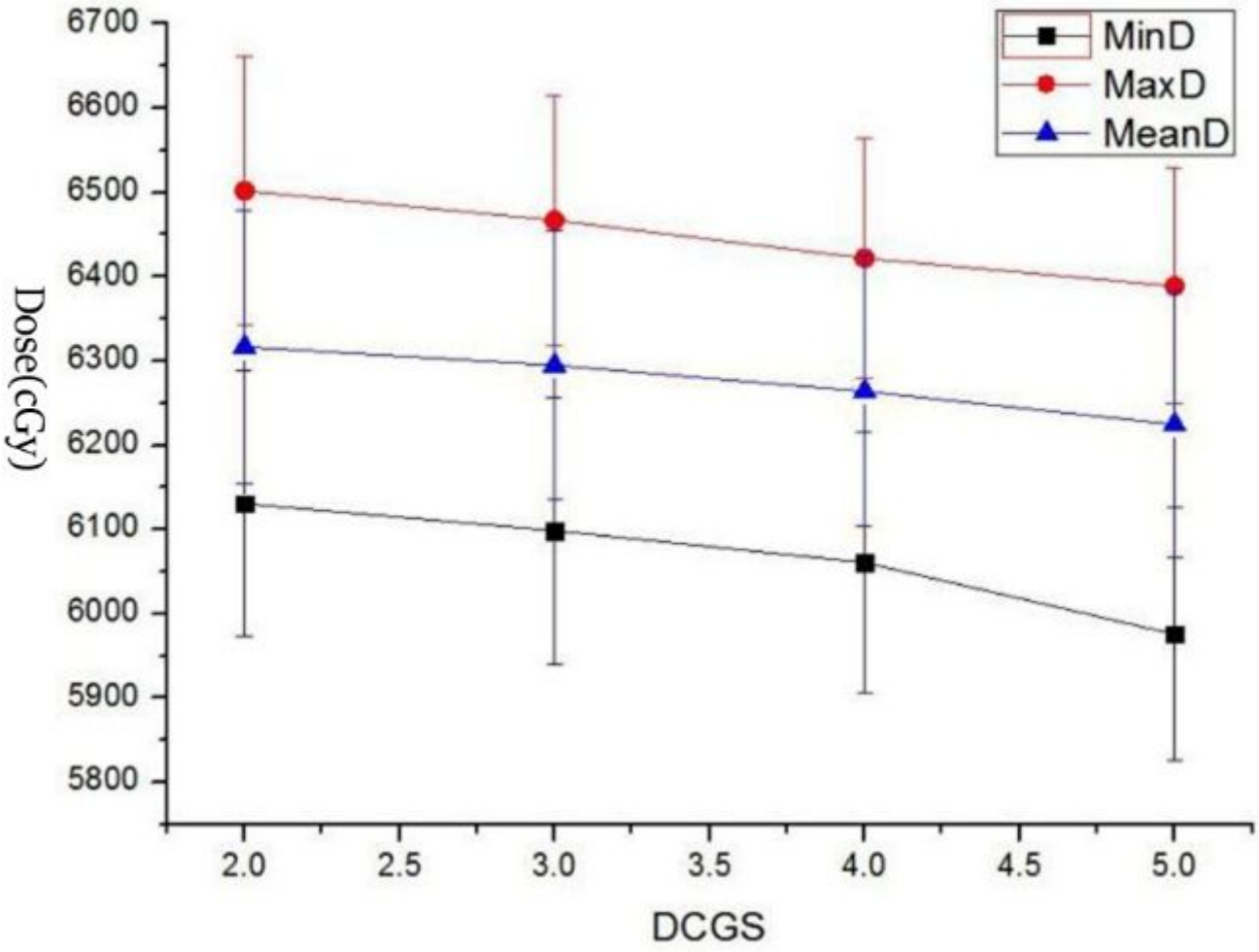

Figure 1

Display of MinD, MaxD and MeanD of PGTV change casused by DCGS

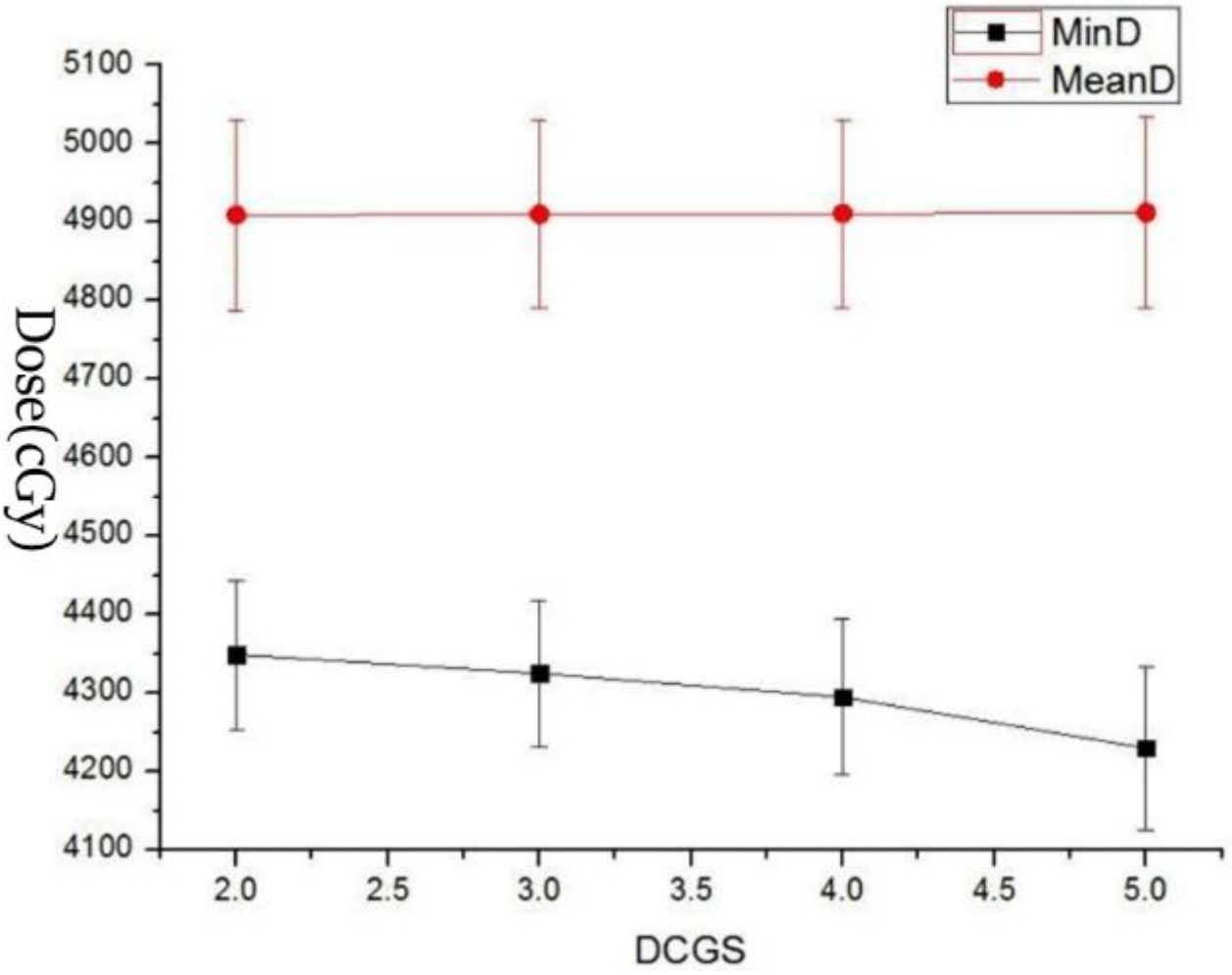

Figure 2

Display of MinD and MeanD of PTV change casused by DCGS

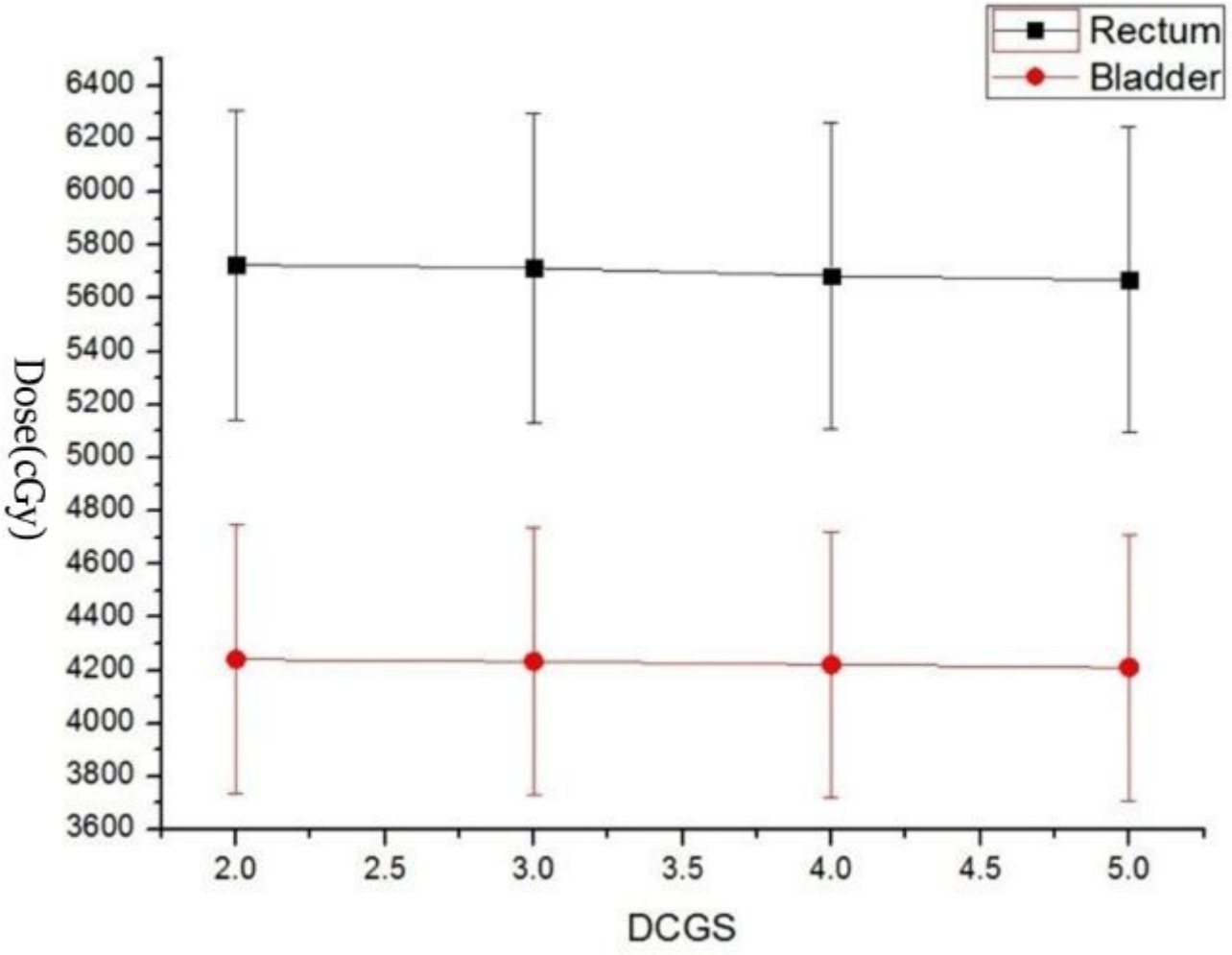

Figure 3

Display of MeanDs of Rectum and Bladder change casused by DCGS

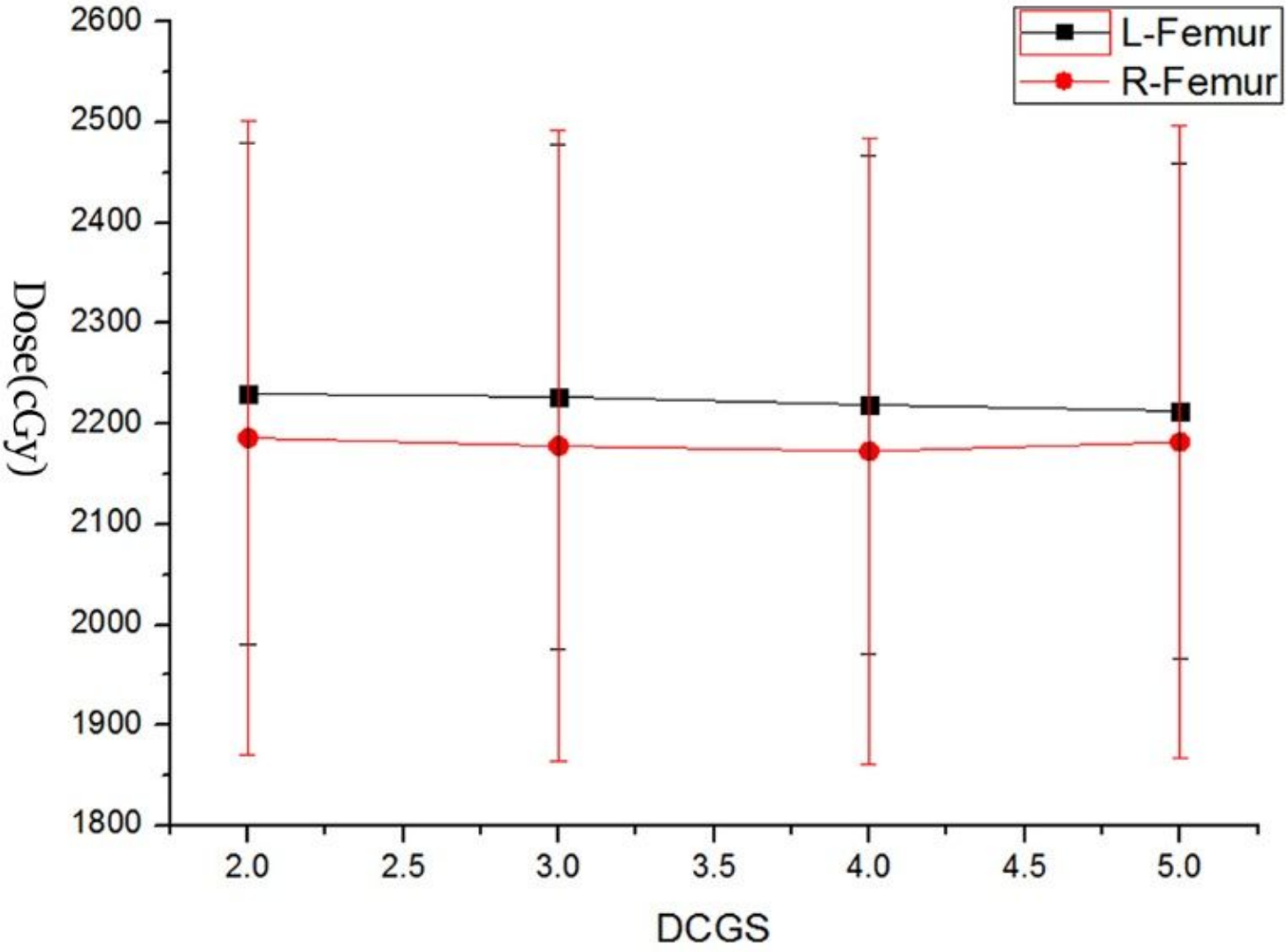

Figure 4

Display of MeanDs of R-Femur and L-Femur change casused by DCGS

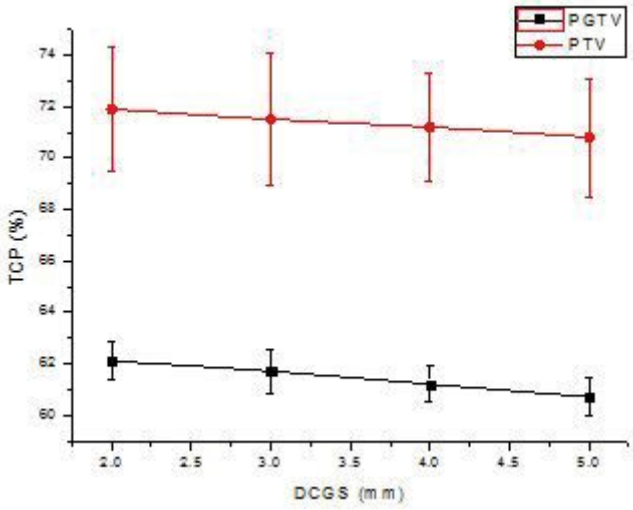

Figure 5

Display of TCP change casused by DCGS

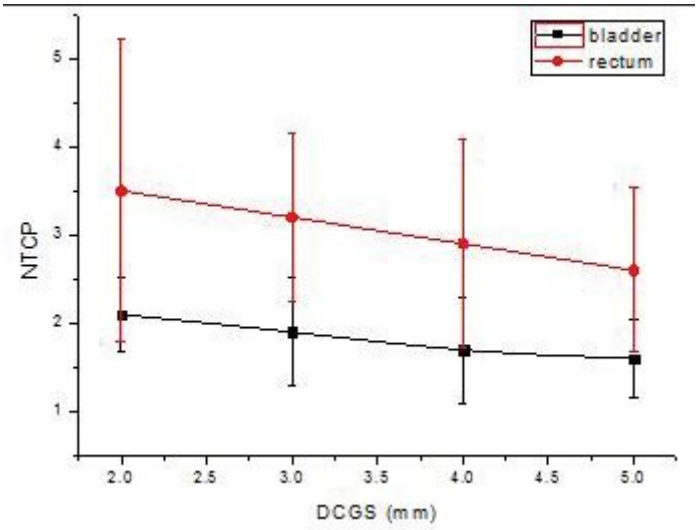

Figure 6

Display of NTCP change casused by DCGS

Figure 7

The map of every structure's paired t test under varied γ analysis standard.

Supplementary Files

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- Equations.docx