Research Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2022.40.006527

Radiotherapy Wedge Filter AAA Model 18 Mev-Dose Delivery 3D Simulations with Several Software Systems for Medical Physics Applications

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ARTICLE INFO

Received: December 21, 2021

Published: January 11, 2022

Citation: Francisco Casesnoves. Radiotherapy Wedge Filter AAA Model 18 Mev-Dose Delivery 3D Simulations with Several Software Systems for Medical Physics Applications. Biomed J Sci & Tech Res 40(5)-2022. BJSTR. MS.ID.006527.

ABSTRACT

Along a series of previous contributions for Anisotropic Analytic Model (AAA) improvements, several exact/approximated formulations/corrections for wedge filters (WF) photon-dose delivery were presented. Namely, exact photon-beam path-length through wedge, exact beam limit divergence angle algorithm, and dose delivery correction Omega Factor for wedge filters. Based on all these algorithms/software, a number of 3D comparative-optional simulations with several software systems are developed for AAA model 18 Mev photon-beam. Explicitly, Matlab, Freemat and GNU Octave systems. In these new simulations algorithm, the corrected AAA photon beam intensity I(z) magnitude modification, fluence and geometrical Omega Factor are implemented. Results comprise a series of optimized 3D graphics with numerical data for AAA photon-dose delivery modified by WF. Computational findings show 3D charts for all these programming systems. New results with 4D Interior Optimization imaging-development are presented with software. Resulting consequences for comparative evaluation of the programming methods with all systems are explained. Radiotherapy Medical Physics applications for wedge filter photon-dose calculations emerge from all the numerical and graphical outcomes. Extrapolated clinical radiotherapy applications are obtained from 2D/3D graphical simulation series.

Keywords: Radiation Dose; Attenuation Exponential Factor (AEF); Simulations; Nonlinear Optimization, Matrix Algebra; Spherical-Spatial Analytical Geometry; Series Approximations; Multi-Leaf Collimator (MLC); Wedge Filter (WF); Conformal Wedge Filter; Anisotropic Analytic Model AAA; Intensity Modulated Radiotherapy (IMRT); Intense Modulated Protontherapy (IMPT); Fluence Factor (FF); Treatment Planning Optimization (TPO)

Introduction

Radiation Therapy has been during recent decades among the most important/frequent clinical methods/treatments for cancer cure, remission, palliative care, lifetime elongation, methastasis treatment, and optimization of oncological therapy for patient life-quality. However, the current tumor treatment trends have evolved/changed in recent years. Chemotherapy, Inmunotherapy, and new Nanoinmunotherapy have emerged as the most powerful methods to eliminate the tumor, obtain a longer patient lifetime, and in many cases, get complete cure/retardation-usually combined one another with/without radiotherapy. In parallel, and spite of these frontline medical advances, radiation therapy has experienced

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also excellent innovations for oncological treatments. Among them, IMRT, IMPT, Carbon-Ion Therapy with their variants have got outstanding advances for tumor growth-control/cure, terminal patients, methastasis treatment, and side-effects reduction [1-8].

Grosso modo, the progresses in cancer therapy can be classified into two groups—which are synergic, complementary and interactive each other. First one is the science-strictly physics, chemistry, bio/molecular-chemistry, pharmacology, and biology group. Second is the computational, imaging, and software framework that is integrated in oncology to optimize, speed up and make efficient all the advances of the first one—for instance, the incorporation of the Artificial Intelligence for radiotherapy treatment planning optimization/selection, TPO. All these improvements are reduced for the increasing difficulty to control the rising incidence/prevalence of almost all tumor types due to multiple factors apart from lifetime elongation. As a pre-hypothesis that has been explained in previous contributions [1-7], Radiation Therapy will remain in clinical future to complete the primary attack to eliminate the most tumor volume and open the field for subsequent Chemo-Inmuno Therapy stages. Complementary, Preventive Medicine has a significant role for cancer incidence reduction and early-stage diagnosis. In a series of previous contributions [1-7], Radiation classical photon therapy AAA model developed by Ulmer and Harder, [1-11], was improved/complemented.

The studies group along 2008-present [1-7], proved a series of geometrical improvements for WF dose delivery with AAA model. These are geometrical Omega Factor, exact path through WF and limit angle for photon-beam through WF [1-7,9-21]. These mathematical formulation developments are based on analytic geometry, integral equations calculus and programming methods [1-8]. Superposition-convolution photon models constitute the base for analytical proton beamlet model for proton therapy dosimetry [12]. This article is focused on 3D computational simulations for WF 18 Mev beam photon-dosimetry with AAA model. The aim is to demonstrate the efficacy/utility of the presented simulations for treatment planning optimization. Software method was done with three different programming systems. Namely, Matlab, GNU-Octave and Freemat. Results comprise a series of 3D imaging and numerical simulations with beam intensity factor I(z) and beam-fluence corrections.

Additionally, a comparative assessment of these computational systems for 3D image processing is shown. Consequently, the novelty of this study comprises several strands. The most important is to prove the utility of the 3D planning optimization/simulation with imaging processing methods. The second is to demonstrate that this utility is efficacious and can be achieved with a number of computational systems available today. Third is the implementation in 3D model simulations of I(z) factor corrections [9]. Complementary, the research shows the usage of these methods for investigation, planning system improvements, and hospital oncology services medical-treatment advances. Therefore, the contribution to medical physics literature can be obtained from these presented results. In summary, this study reports a software programming series of methods to carry out 3D radiotherapy simulations for dose delivery with AAA model and 18 Mev photon spectrum. A number of approximations were applied, but the main objective to prove the utility of 3D dose graphical simulation was reached. The second aim is to show how this can be performed with different computational systems. Namely, Matlab, GNU-Octave and Freemat. Medical Physics applications both for clinical radiotherapy treatment planning optimization and radiotherapy physics modelling research come from all the article results.

Mathematical and Computational Methods

Section is divided into two sub-sections. First the AAA model mathematical framework is presented. Secondly, the algorithms computational software and program implementation is explained.

Mathematical and Algorithmic Development

Along a series of papers, [1-11], the equations of the AAA original model photon-dose with WF were calculated. AAA model was named Superposition-Convolution for its mathematical formulation. That is, the term ‘Superposition’ comes from the sum of three Gaussians into the integral. The term ‘Convolution’ describes the mathematical transformation carried out into the Dose-Deposition Kernel at the Integral. Based on this number of previous articles, [1-7,16-29], the WF dose delivery in water without tissue-attenuation corrections is,

$$D(x,y,z)=I(z)\int_{-a'}^{a'}\int_{-b'}^{b'}\Phi_W(u,v,z)\,x\ldots$$
$$\ldots x\sum_{K=1}^{K=3}\frac{C_K}{\pi\,\sigma_K^2}\,x\,e^{\left[-\left[(x-u)^2+(y-v)^2/\sigma_K^2\right]\right]}du\,dv\,; \quad (1)$$

where I(z) is the area integral of the dose over a plane perpendicular to the z-axis at depth z, normalized to one incident electron, σ(z) is the depth-dependent mean square radial displacement, x, y, z are the coordinates of the dose-delivery point at beam-output coordinates system, u, v, z, are the coordinates of photon-fluence at depth z, a, b, are the field-size magnitudes at depth z, C_K are optimization parameters resulting for a triple Gaussian function setting, ΦW is the photon fluence modified for WF, a’(z) =a(l + z/F), b’(z) =b(1 + z/F) are the halfside lengths projected into depth z, with F as the source-surface distance (SSD). All these parameters are defined in [30,31].

The modified fluence factor (FF) for WF reads,

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$$\Phi_w(\text{u,v,z}) = \Phi_U(\text{u,v,z})\, X \ldots$$

$$\ldots . X e^{\left[-\mu_W X\left[L \pm \frac{CU}{F+Z} X\left(\frac{\sin\alpha}{\cos(\alpha+\phi)}\right)\right]\right]}$$ with Φ_w (u,v,z)as WF modified fluence. (2)

where C is the distance in z-coordinate from source to WF surface, L is half-length of WF for y coordinate, and $\Phi_U = \Phi_0 / (1 + z/F)^2$ according to [30,31]. The source fluence is modified primarily for the dose-delivery depth z and secondly by the WF parameters [1-11, 20,21]. That is, WF modifies the photon-beam energy spectrum. This model of WF was proven be not totally exact [1-7], because the exact path through WF was calculated approximately [1-7]. Then, in [1-11,20,21], the demonstration of the approximate path and exact path was presented. It was determined an Omega correction Factor (OF) for the Equation 2 [1-7] as follows,

- **Proposition 1** [Casesnoves, 2014, 1-7]. - Geometrical Omega Factor, namely, $[\Omega]_F$, can be expressed, [my refs] in multiple geometrical-algebraic forms, and one suitable for integration is,

$$[\Omega]_F = \left[1 + \frac{\tan^2\varphi_2}{1+\tan^2\varphi_1}\right]^{\frac{1}{2}}; \qquad (3)$$

where Φ_1 and Φ_2 are the geometrical angles for computation defined in Figure 1 and [1-7]. Calculation and programming of these angle ranges is laborious [1-7]. Proof: Complete mathematical development at [1-7]. The extent geometrical elaboration of Omega Factor is shown in Figure 1, presented in previous contributions [1-7].

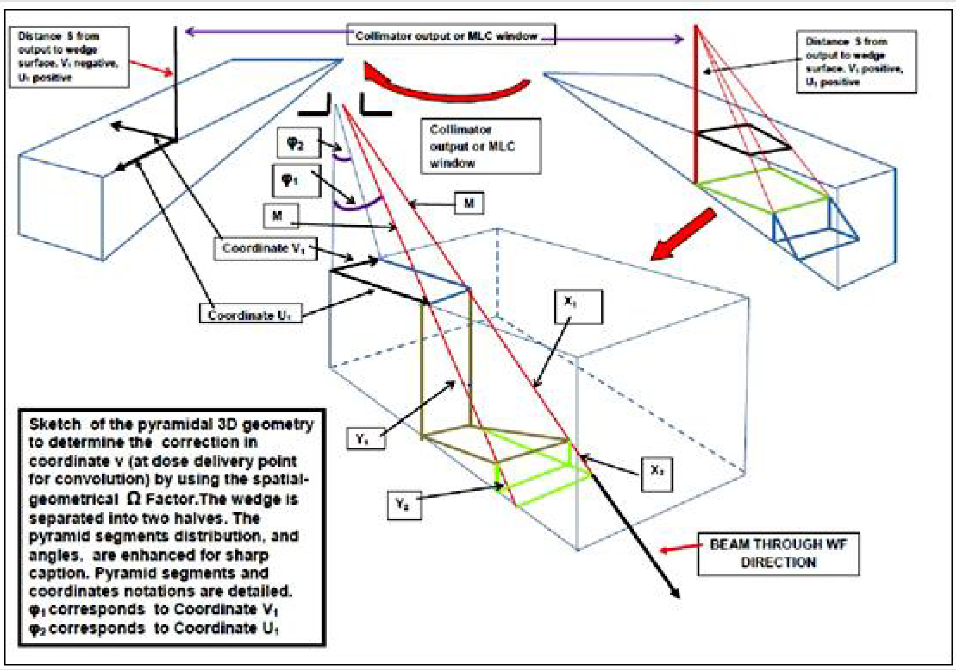

Figure 1: From [refs], the geometrical exact Omega Factor development. Analytical geometry calculations are rather laborious, [1-7,16-23]. This image is included from previous studies because it shows clearly the Omega Factor geometrical analytic method.

The integral equation for AAA in water with 3D AEF Omega Factor $[\Omega]_F$ is as follows,

$$D(x,y,z) = \frac{I(z)\, A}{4(1+z/F)^2}\, x \ldots$$

$$\ldots x \int_{-a'}^{a'}\int_{-b'}^{b'} \Phi_\Omega \quad x \ldots$$

$$\ldots x \sum_{K=1}^{K=3} \frac{C_K}{\pi\, \sigma_K^2}\, x\, e^{\left[-\left[(x-u)^2+(y-v)^2/\sigma_K^2(z)\right]\right]}\, du\, dv;$$

$$\textit{with modified fluence in } [\Omega]_F,$$

$$\Phi_W(u,v,z) = \Phi_0(u,v,z)\, x \ldots$$

$$\ldots x\, e^{\left[-\mu_W x\left[L \pm \frac{Cu}{F+z} x\left(\frac{\sin\alpha}{\cos(\alpha+\varphi)}\right)\right]\right] x\left[[\Omega]_F\right]}; \qquad ; \qquad (4)$$

where parameter A is defined for WF [30,31] as,

A = exp[-μ_W L x (sinα/ (cos (α + φ)))]. Parameters μ_w (WF material parameter), α (WF angle) and φ (photon-beam divergence angle) are defined at [1-11,20,21]. Development of Equations 1-4 are extensively presented in [1-7]. Finally, the solution, exact, complete, geometrically corrected with Omega Factor, and analytical of this integral equation [Casesnoves, 2015, April, Philadelphia], reads,

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$$D(x,y,z)=\frac{I(z)\,A}{4(1+z/F)^2}\,x\sum_{K=1}^{K=3} e^{\left[\sigma_K^2(z)S^2-2Sx\right]}\ldots x$$
$$\ldots x\left[\left[Erf\left(\frac{y+b'}{\sigma_K(z)}\right)\right]-\left[Erf\left(\frac{y-b'}{\sigma_K(z)}\right)\right]\right]\ldots x$$
$$\ldots x\left[\left[Erf\left(\frac{x+a'+\sigma_K^2(z)S^2}{\sigma_K(z)}\right)\right]-\left[Erf\left(\frac{x-a'-\sigma_K^2(z)S^2}{\sigma_K(z)}\right)\right]\right];$$
$$where\ S=S\left([\Omega]_F\right),\ and\ A=A\left([\Omega]_F\right); \qquad (5)$$

Constants are given following the previous equations. This formula is an Omega Factor correction from the equations [7,2-5,22-26] of classical AAA model [8,9]. The S and A variables depend on Omega Factor and were mathematically developed in previous numerical computation programming and 3D Graphical simulations [1-7].

Software-Programming Method

The computational method is based on previous software works [1-8,16-23]. This integral equation complete analytical solution, Eq. 5 will be correctly simulated in dosimetry-matrices from 100 x 100 dimensions to 1500 x 1500 dimensions in the following sections and compared with simulations of equations [11-15] of classical AEF [1-7] in AAA model foundations. Further development of Equations 1-5 is extensively presented in [1-7,16-23]. Table 1 shows numerical values implemented for algorithms programming. Table 1 shows the main numerical data for the 3D simulation graphics. The magnitude of Omega factor is about 1.12, for a WF of 15 degrees, and increases with the WF angle till 45° [1-7,16-23]. Note that this apparently small value of Omega Factor becomes propagated by multiplication other constants in formulation and the result is a change of 3D dose delivery magnitude as shown in imaging simulations.

The structure of the program comprises the summatory of every part of Eq. 5. Firstly, these parts of erf functions are set independently one by one. Secondly all of them are summed. Finally, the resulting numerical values are set in the imaging subroutine. These individual erf parts are proven in Table 2. In this study, they can be implemented in Matlab, GNU-Octave, or Freemat. Every system requires an specific modification of the main program to obtain correct simulations. Imaging processing tools and subroutines/options vary in every system. Table 1 shows all the implementation data with corrections from Section 3. Table 2 shows the new model functions [based in erf function parts for WF] adjusted/improved for setting the new functional software.

Table 1: AAA model main parameters for 3D Graphical simulations [1-7, 9,10,11, 54, 55].

COMPUTATIONAL RADIOTHERAPY DATA				
Photon-beam Divergence angles, WF dimensions [cm] and angle	Sigma constants [adimensional] for Model Gaussians at Siemens LINAC Mevatron KD2, output 18 MeV	Photon Beam Intensity [Gy cm^2] and Fluence [Number photons/cm^2/Gy]	Depth Z=15 cm with summatory Model constants [adimensional]	WF correction Omega Factor [Ω]F [adimensional]
WF Angle=15° 12 x 12 [cm]	σ1=0.177849	I(z)=17.6951 x 10-12 [corrected [9]]	C1=0.566	Example, For z=15 cm and C1 part [Ω]F=1.1181
φ1=30°	σ2=1.304278	Φ0 ϵ [4.16 x 109, 2.82 x 1010]	C2=0.254	
φ2=30° [approximately]	σ3=1.259932	[corrected [10,11]]	C3=0.189	

Note: Data from AAA algorithm foundation in water, [9,54,55], whose numerical computational software used for constants and parameters optimization was Monte Carlo Code EGS-4 and curve fitting MAAFS from CERN (European Union Center for Nuclear Research).

Table 2: Program software parts numerically calculated for Eq. 5 with new corrections [1-7,9,10,11,16-23,54,55]. The data from Section 2, Table 3, was implemented.

CORRECTED NUMERICAL METHOD FOR COMPUTATIONAL PROGRAMMING IMPLEMENTATION (18Mev, Z=15 cm) with [Ω]F
Dose summatory element 3D (Omega Factor) D_{Ω} [i=1,..,3] (x,y,z)
D_{Ω} [i=1] (x,y,z) = 0.7745 • 10-2 • exp(0.001109-0.0714 x) • • [Erf [(x+13.8010)/0.177849] - Erf [(x-13.8010)/0.177849]] • • [Erf [(y+13.8010)/0.177849] - Erf [(y-13.8010)/0.177849]]
D_{Ω} [i=2] (x,y,z) = 0.3413 • 10-2 • exp(0.0021686-0.0714 x) • • [Erf [(x+13.8010)/1.304278] - Erf [(x-13.8010)/ 1.304278]] • • [Erf [(y+13.8010)/ 1.304278] - Erf [(y-13.8010)/ 1.304278]
D_{Ω} [i=3] (x,y,z) = 0.2633 • 10-2 • exp(0.0020237-0.0714 x) • • [Erf [(x+13.8010)/1.259932] - Erf [(x-13.8010)/ 1.259932]] • • [Erf [(y+13.8010)/ 1.259932] - Erf [(y-13.8010)/ 1.259932]

I(z) Corrections for AAA Model

After the AAA model foundation, several I(z) important corrections were developed by Ulmer and Harder [9]. Additionally, during 2008-15, a series of geometrical improvements for WF were published [Casesnoves, 1-7,16-23]. These are Omega Factor, Eq. 3, exact path through WF and limit angle for photon-beam through WF [1-7,16-23]. Omega Factor extent calculations and analytical geometry are shown in (Figures 1 & 2). The I(z) corrections were numerically important as I(z) magnitude varied in one magnitude order less. Namely, from 10^{-11} till 10^{-12}. The corrections were mathematically done, [9], by an exponential-fit in the function I(z) as follows,

$$I(Z) = Ae^{-az} - Be^{-bz} \quad (6)$$

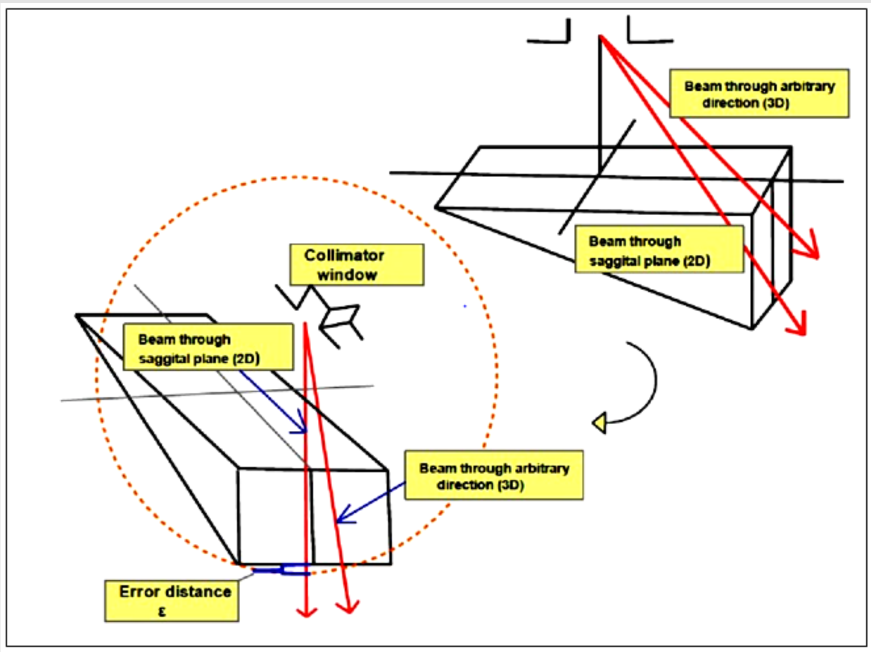

Figure 2: From [1-7], geometrical difference/error-path when using 2D approximation compared to 3D determination. If we take always the AEF approximation of Eq.2, in the sagittal plane, there is an error for less magnitude (blue brackett) in the path-distance through the wedge. The geometrical exact Omega Factor development. Analytical geometry calculations are rather laborious, [1-7,16-23]. This image is taken from previous publications for paper understanding clarity.

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where parameters A, B, a, b, are graphically shown in [9] related to depth-parameter z. Function constants $\sigma_k(z)$ were found with no significant numerical differences in photon spectrum [9]. As a result, from this numerical modification, it was found that l(z) changes by up to 0.7 % in the I(z) maximum and up to 5 % at large depth. Table 3 shows these corrections implementation for the 3D simulation study here, with one magnitude order difference [1-7,9,16-23]. In these simulations fluence [10,11] is set as (particles number/cm^2 /Gy). Hence, the numerical modification for fluence factor (FF) magnitude, according to Eqs. 1-5, (Tables 1 & 2), is significant [10,11]. That is, FF ϵ [4.16 x 10^9, 2.82 x 10^{10}], and it is taken the average. Just remark that the objective of the research is to demonstrate utility and efficacy for clinical/research 3D Graphical Optimization with several systems, not a dose-delivery extremely precise calculation [32-55]. However, acceptable numerical dose delivery data were obtained, (Figures 3-12).

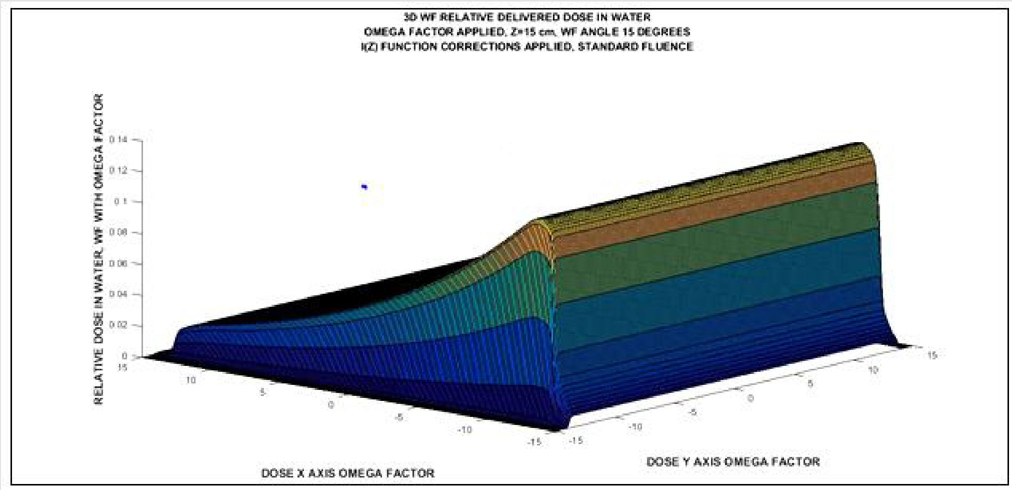

Figure 3: Matlab simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have about 103 elements. Imaging Processing Method 1.

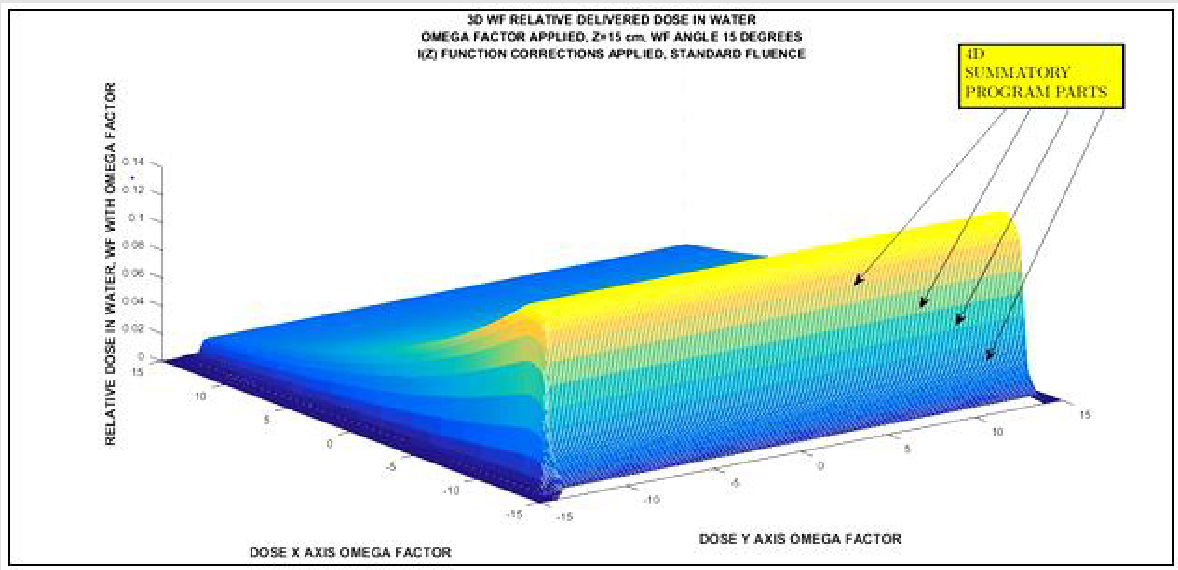

Figure 4: Matlab simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have more than 10^3 elements. Imaging Processing Method 2.

Table 3: I (z) and Fluence numerical corrections [1997,9] related to [54,55,1995-6]. Note the one magnitude order significant difference. This factor has significant influence in photon-dose delivery with/without beam modification devices.

I(Z) AND FLUENCE CORRECTIONS IMPLEMENTED FOR 3D SIMULATIONS [18MEV]				
	PREVIOUS STUDY	PRESENT STUDY	COMMENTS	Fluence [Number photons/cm2/Gy]
I(z) [Gy cm2]	13.38 10^{-11}	17.6951 10^{-12}	Significant magnitude order difference in spectrum	Φ0 ϵ [4.16 x 10^{9}, 2.82 x 10^{10}] [corrected [10,11]]

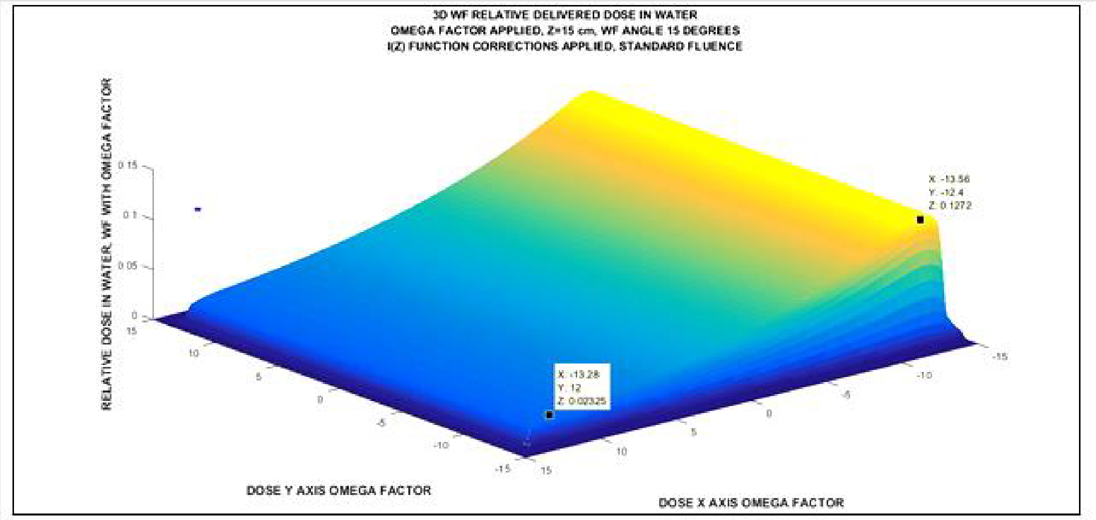

Figure 5: Matlab simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Numerical data that can be obtained, pictured inset, with image processing method. Relative dose in one-percent, at Z axis, X coordinate at WF, Y coordinate at WF, and program part relative dose. Fluence magnitude according to Section 3. Matrices for Image Processing have about 10^3 elements. Imaging Processing Method 1.

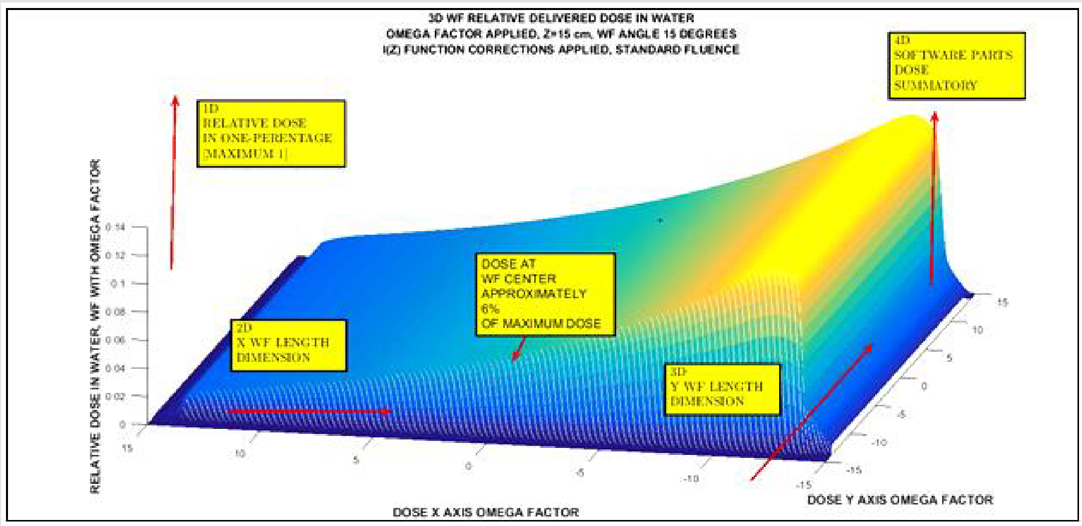

Figure 6: Matlab simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Numerical data that can be obtained in simulation comprises four dimensions. Namely, relative dose in one-percent, X coordinate at WF, Y coordinate at WF, and program part relative dose. Fluence magnitude according to Section 3. Matrices for Image Processing have about 10^3 elements. Imaging Processing Method 1.

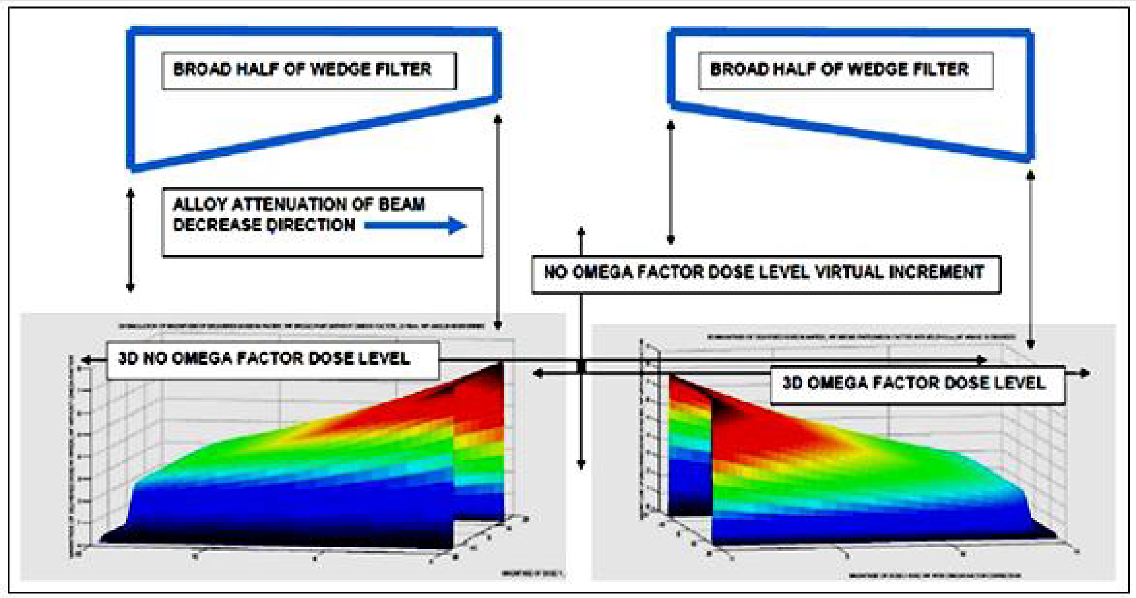

Figure 7: From [1-7], comparative Matlab simulations 3D image for 18Mev photon-beam at 15 cm depth-dose with/without Omega Factor. Matrices for Image Processing have 10^6 elements. Computational-Graphical simulation-proof of virtual dose error caused by 2D approximated integral equation solution. This simulation is important, because it proves sharply the virtual dose error that is given by the AAA algorithm when using AEF in 2D. That is, the planner system calculates a higher dose compared to the true dose, and this error causes under-dosage on the tumor. On the opposite, 3D planning with Omega Factor results in more precise dose for radiotherapy optimization -with the significant mention that all these calculations and simulations are carried out in water with the foundation AAA model. The simulation is done in the thick part of the wedge, because recent advances have been useful to find a difference in the sign of angle φ1 for the thin half of the WF –this extent analytical-geometry calculation will be explained and simulated in next contributions. The most important objective of this article was to demonstrate the correct approximations and mathematical development together with the computational proof that validates the difference of magnitude between 2D AAA in water and 3D with Omega Factor dosimetry in the same conditions. Note that this picture belongs to former publications without numerical Section 3 corrections.

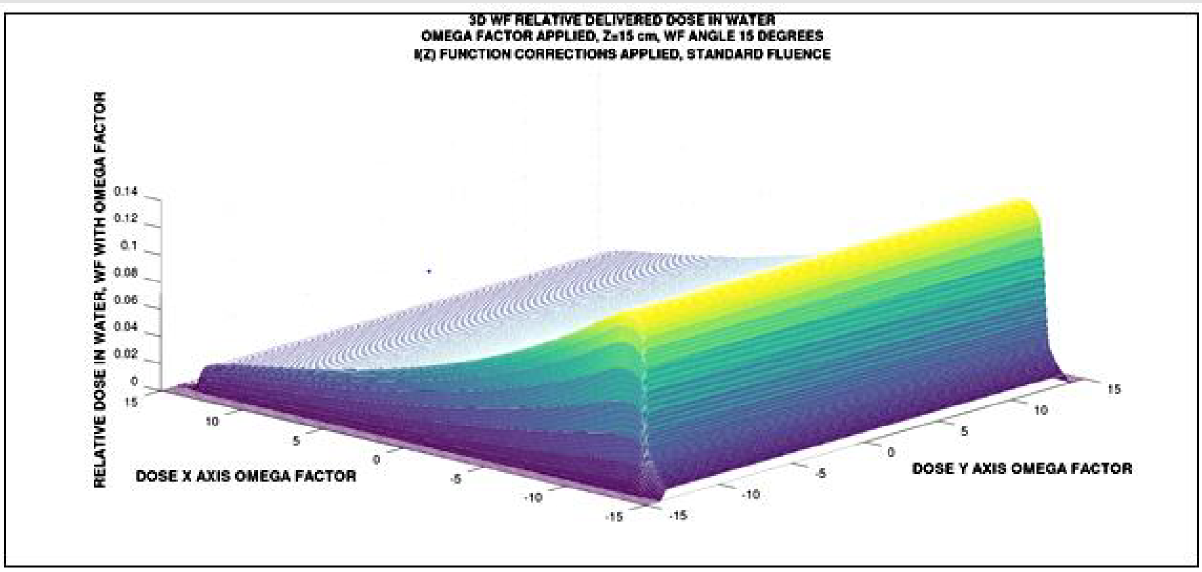

Figure 8: GNU Octave simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have more than 10^3 elements. Imaging Processing Method 1. Image has suitable quality. Running time is longer [≈ 20 s] than Matlab. Software design is very similar.

DOI: 10.26717/BJSTR.2022.40.006527

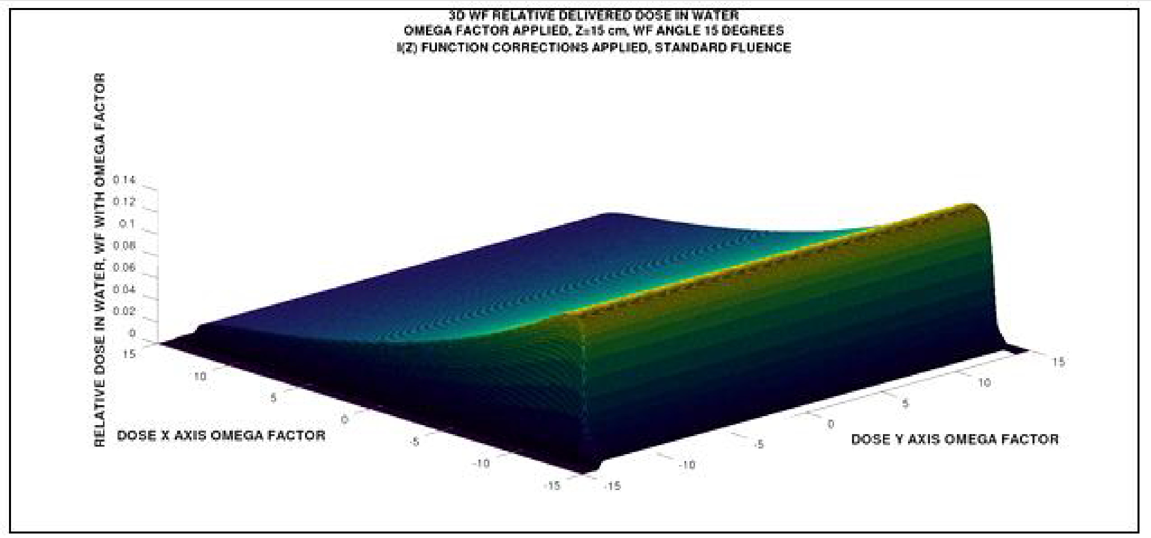

Figure 9: GNU Octave simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have more than 10^3 elements. Imaging Processing Method 2. Image has suitable quality. Running time is longer [≈ 30 s] than Matlab. With Method 2, the program setting for labels are different.

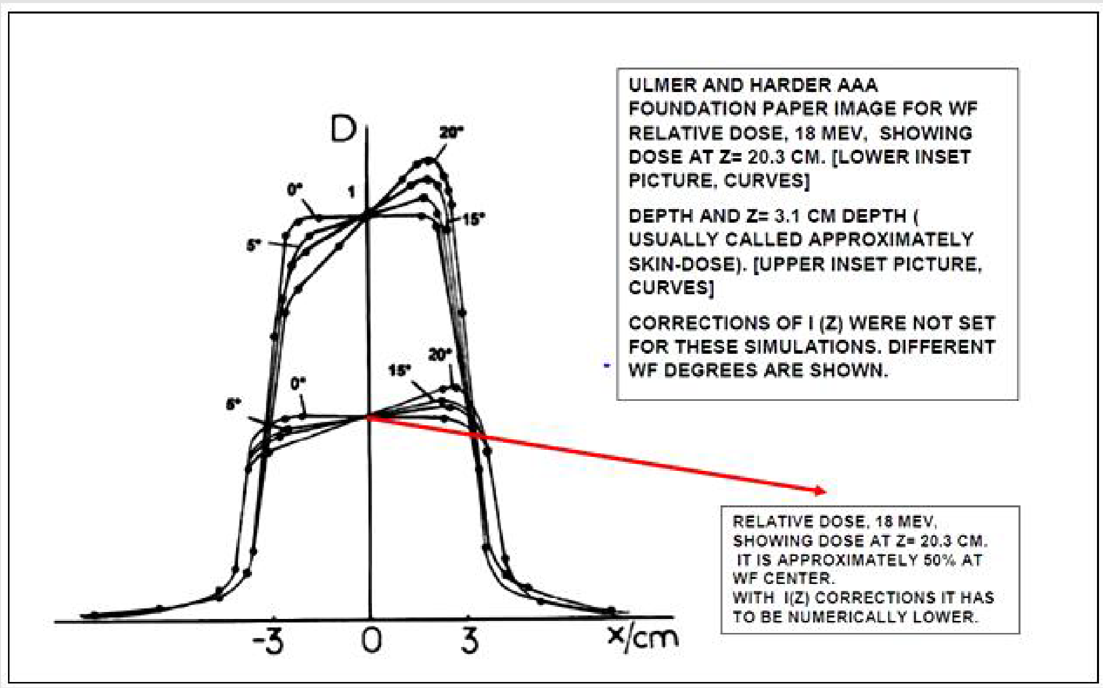

Figure 10: From ref [54], it is sketched a graphical composition from its Figure 5 [Ulmer and Harder 1996]. In this 2D simulation, with non-corrected I (z) function, the dose for WF,18 Mev, at z=20.3 cm (deeper than 15 cm) is around 50% of maximum dose. Numerical 3D Graphical simulations for this study show a dose of about 20% related to maximum dose with I(z) adjustments. In addition, when field size increases, as it is here [12 x 12 cm], compared to [-3 , 3], the relative dose generally decreases. Therefore, it is straightforward to guess that approximations of the numerical and imaging software/model are acceptable. Important remark: the very good image/simulation from Ulmer and Harder [54] has a numerical inconsistency at coordinate x=0. That is, the dose at center through WF of different angles cannot be exactly equal. The probable reason is that in the graphical sketch the points at around (-3) and (+3) were matched with curves. That caused quality of dose for different angle WF at x=0 and along D axis.

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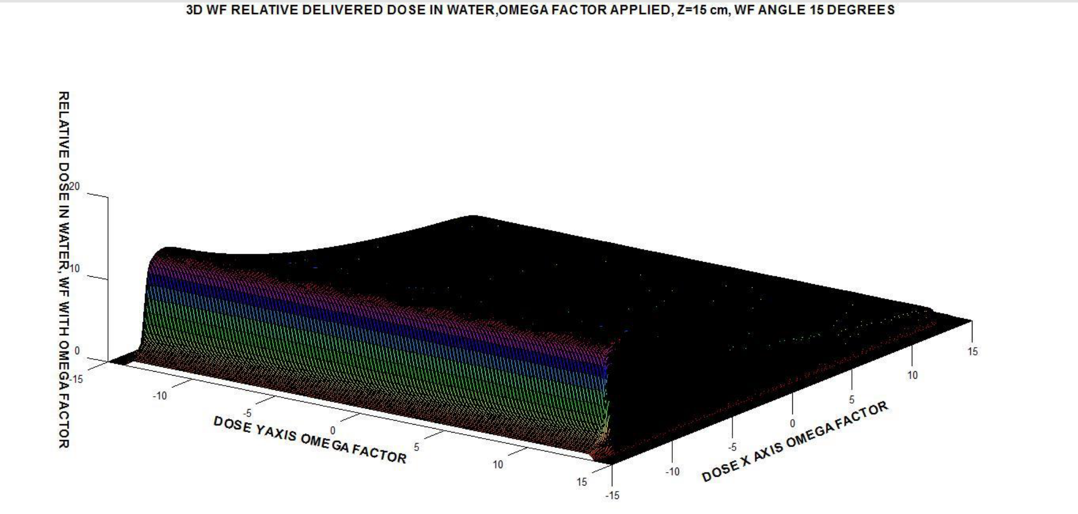

Figure 11: Freemat simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have more than 10^3 elements. Imaging Processing Method 2 [the unique possible in Freemat]. Image is good but slow to obtain, 10^2 scale factor at Z axis was necessary to get a visible 3D image—that is, expressing dose in percentage. Running time is longer [≈ 40 s] than Matlab and GNU-Octave. With Method 2, the program setting for labels are different. The imaging processing tools are much slower/difficult than Matlab and GNU-Octave. Color and program parts definition are worse than Matlab and GNU-Octave. Relative dose is not higher than 20% maximum dose.

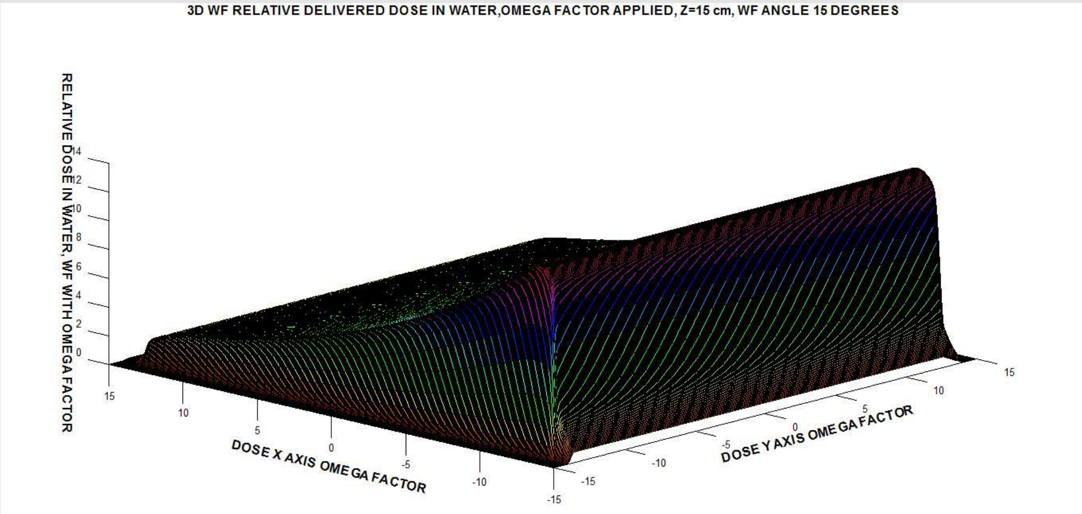

Figure 12: Different view from Fig 11, for showing program parts. Freemat simulation 3D image for 18Mev photon-beam at 15 cm depth-dose with Omega Factor and I(z) corrected. Fluence magnitude according to Section 3. Matrices for Image Processing have more than 10^3 elements. Imaging Processing Method 2 [the unique possible in Freemat]. Image is good but slow to obtain, 10^2 scale factor at Z axis was necessary to get a visible 3D image—that is, expressing dose in percentage. Running time is longer [≈ 40 s] than Matlab and GNU-Octave. With Method 2, the program setting for labels are different. The imaging processing tools are much slower/difficult than Matlab and GNU-Octave. Color and program parts definition are worse than Matlab and GNU-Octave.

The model that is implemented in simulations is the original AAA one with Omega Factor [Casesnoves, 2015, 1-7,16-23] WF geometrical correction for water. This model is the base for further developments carried out in foundations [9,54,55]. Besides and later on, superposition-convolution analytical models for proton therapy emerged from this AAA mathematical framework [12]. Among them, tissue inhomogeneities, scatter radiation, or contaminating electrons [9-11]. That is, primary photons and extra-focal photons, scattered in the flattening filter or the beam collimator, flattering filters, jaws, blocks, multi-leaf collimator, and the group of direct dose delivery beam modificators, such as WF, satellite filters, shielding blocks, rectangular satellite filters, etc [14,8-11]. According to all these physical constraints, in practical clinical medical physics treatment planning implementation dose is calculated,

$$TOTAL\ DELIVERY\ DOSE = [primary\ photons]\ DOSE + [extra-focal\ photons]\ DOSE + [contaminating\ electrons]\ DOSE \quad (7)$$

3D MATLAB WF Simulations Results

This section shows the Matlab results for 3D Treatment planning Optimization images and numerical data, (Figures 3-7) with two software methods. (Figure 7) is a comparative sketch to clarify the difference of dose between classical AAA equations and equations modified by Omega Factor [1-7]. The fourth dimension of photon dose is explained in (Figure 6).

3D Gnu-Octave WF Simulations Results

This section shows the GNU-Octave results for 3D Treatment planning Optimization images and numerical data, (Figures 8-10) demonstrates and explains the numerical results acceptable precision. Two software methods are shown. Figure 10 is a comparative sketch with [55] to clarify the small difference of dose between classical AAA WF simulations equations and these 3D imaging simulation results.

3D Freemat WF Simulations Results

This section shows the Freemat results for 3D Treatment planning Optimization images and numerical data, (Figures 11 & 12). For these imaging simulations, Freemat is not as much suitable than Matlab abd GNU-Octave.

Comparative Evaluation

Table 4 shows a comparative assessment for the applied systems. In terms of practical visualization, all systems can be considered acceptable. However, MATLAB makes the best and fast images with data adquisition facilities. The lowest is Freemat, and for this system it is necessary to scale the axes magnitudes to display suitable images. The factor of personal preferences of the programmer for system choice can be considered also. Freemat has exclusively one subroutine imaging option for this 3D simulations.

Clinical Medical Physics Applications

Table 5 shows a resume of principal applications of the results and software methods. Extrapolated applications, e. g. IMRT or IMPT, can also be guessed for future clinical/research radiotherapy developments.

Table 4: Assessment of the selected systems for 3D imaging simulations.

COMPUTATIONAL COMPARATIVE RESULTS						
Application → / System ↓	Overall Imaging Quality	Imaging Vision Tools	Imaging Data Adquisition	Imaging Display Time [s]	Imaging Spatial Rotation	Imaging Display Subroutines
MATLAB	Optimal	Very Good	Very good	04-Aug	Very good	Several
OCTAVE	Very Good	Good	Average-good	Jun-15	Good	Several
FREEMAT	Average-good	Average, It is reduced to one subroutine	Average	Aug-18	Slow	1

Table 5: Radiotherapy Medical Physics study applications.

CLINICAL MEDICAL PHYSICS APPLICATIONS				
TYPE	CLINICAL	RESEARCH	MIXED	COMMENTS
Treatment planning optimization	Pre-dose delivery plan	Modelling improvements	Clinical modifications after research	In the past, planning system was in 2D LINAC
OPTIMIZATION	Accuracy of photon-dose	New LINACs Extrapolation to IMRT, IMPT	Clinica/laboratory trials for new LINACs	Rather difficult to set correctly new modifications and manufacture new LINACs
Theoretical new models	When new models are proven better, the better dose accuracy	Theoretical Radiotherapy Physics model investigation, extrapolation to IMRT, IMPT	Clinical/laboratory trials for new models	Radiotherapy models have evolved significantly

Discussion and Conclusion

This study has shown advantages/inconvenients for 3D computational simulations of WF dose delivery with a 18 Mev photon beam at 15cm depth-dose with three computational software-systems. These 3D simulations are corrected in approxitions for several reasons. I(z) important corrections were set in software codes [9]. Fluence has also been modified for better [10,11]. Others are Omega Factor, Eq. 3, exact path through WF and limit angle for photon-beam through WF [1-7,12-19]. In terms of practical visualization, all systems can be considered acceptable. However, Matlab makes the best and fast images with data adquisition facilities. The lowest is Freemat, and for this system it is necessary to scale the axes magnitudes to display suitable images. MATLAB provides with good-quality images, and is considered the best system for these type 3D simulations.

GNU-Octave visualization and 3D plots for photon-dose delivery is good also, while Freemat can be considered a bit more difficult and slower. However, in general, all systems studied are considered acceptable. The selection of any of them depends on computational facilities, programming skills, and image-quality/ vision processing requirements. Tissue inhomogeneities, scatter radiation, or contaminating electrons modifications for 3D graphics have not been applied. The study has proven that there are multiple computational systems to simulate 3D WF conventional photon dose delivery with AAA model—and extrapolation to other models, included IMRT and IMPT. Matlab, GNU-Octave, and Freemat are suitable systems in order of acceptable functionality. High-quality 3D imaging processing methods were proven. 4D image settings constitute an innovation compared to previous contributions [1-7,12-19]. For simulations of dose delivery without beam-modification devices, the method is also useful/efficacious.

MATLAB and GNU-Octave shows 2 types of imaging subroutines, while Freemat only one. Medical Physics applications are theoretical and clinical-practical. Theoretical ones involve research in TPO, simulations, implementation in software planning systems, LINAC calibration improvements, photon-dose theoretical-experimental fitting, development/comparison of new optimization methods, and several others. Clinical-practical comprise TPO routine work, clinical medical physics improvements for service functionality, training in delivery simulations, etc. In summary, this imaging radiation therapy WF study shows modern systems for 3D photon-dose simulation. Imaging processing and computer vision methods are demonstrated. Multiple applications in Clinical and theoretical Medical Physics and Bioengineering emerge from the results.

Scientic Ethics Standards

This contribution is based on Graphical Visualization and Software Optimization methods for radiotherapy modelling improved from previous articles [1-7,12-19]. Graphical-Optimization Methods were created by Francisco Casesnoves in December 2016. The image processing and computer vision tools programs and special software to obtain new dosimetry images positioning, panoramic vision, enhancement of selected WF dose-deposition parts, or imaging tiles optimization was originally developed by author in Matlab, GNU-Octave and Freemat. This advanced article has a few previous paper formulation information, [1-7,12-19], whose inclusion is essential to make the contribution understandable. (Figures 1, 2 & 7) were taken for essential understanding from [1-7,12-19]. This study was carried out, and their contents are done according to the European Union Technology and Science Ethics. Reference, 'European Textbook on Ethics in Research'. European Commission, Directorate-General for Research. Unit L3. Governance and Ethics. European Research Area. Science and Society. EUR 24452 EN. Also based on The European Code of Conduct for Research Integrity. Revised Edition. ALLEA. 2017. Revised Edition. ALLEA [27,28].

The applications section has some mandatory words from previous contributions. This research was completely done by the author, the software, calculations, images, mathematical propositions and statements, reference citations, and text is original for the author. When a mathematical statement, proposition or theorem is presented, demonstration is always included. The Omega Factor demonstration is not included as it is rather large and can be found at [1-7]. The primary Omega Factor calculations were obtained during MSc Thesis in 1999. The article is exclusively scientific, without any commercial, institutional, academic, political, religious, or economic influence. When anything is taken from a source or previous contribution, it is adequately recognized [29-59].

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ISSN: 2574-1241

DOI: 10.26717/BJSTR.2022.40.006527

Francisco Casesnoves. Biomed J Sci & Tech Res