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ON THE CORRECTION OF DOSE PROFILE DISCREPANCIES BY INTRODUCING AIR IN THE DERIVATION OF AN ELECTRON SPECTRUM

Sobre la corrección de discrepancias del perfil de dosis por introducción de aire en la derivación de un espectro de electrones

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Abstract

Knowledge of the energy spectrum of an electron beam is relevant for accurate dose calculation in radiotherapy. In previous works, it has been possible to reconstruct the electron spectrum of various clinical energies (6, 9, 12 and 15 MeV) within the typical percentage of clinical acceptance (Pa > 95 %) according to the gamma index (GI) (2 %/2mm), for both depth dose percentages (PDD) and dose profiles (DP), except for 6 MeV profiles. Therefore, the purpose of this work was to introduce air between the radiation source and the phantom surface to simulate both the monoenergetic PDDs necessary in the reconstruction of the spectrum of a 6 MeV beam and to obtain the PDD of this spectrum. Validation was performed using the gamma index with the typical threshold for clinical acceptance. The results showed that the PDP of the vacuum spectrum had a better agreement than the PDP of the air spectrum (Pa = 100 %), with respect to the measured PDD (Pa = 97 %). Regarding the PD, the introduction of air improved the agreement in clinical interest but not enough to reach the acceptance percentage. It is concluded that this technique does not seem to be a good alternative to correct the discrepancies in the field edges between the DP of an inversely reconstructed spectrum and the measured DP.

Key words: *inverse reconstruction, electrons, air, gamma index, dose profile.*

Resumen

El conocimiento del espectro de energía de un haz de electrones es relevante para el cálculo preciso de la dosis en radioterapia. En trabajos anteriores, se ha conseguido reconstruir el espectro de electrones de varias energías clínicas (6, 9, 12 y 15 MeV) dentro del porcentaje típico de aceptación clínica (Pa > 95 %) según el ´índice gamma (IG) (2 %/2mm), tanto para los porcentajes de dosis en profundidad (PDP) como para los perfiles de dosis (PD), excepto en perfiles de 6 MeV. Por tanto, el propósito de este trabajo fue introducir aire entre la fuente de radiación y la superficie del fantoma para simular tanto las PDP monoenergéticas necesarias en la reconstrucción del espectro de un haz de 6 MeV como para obtener la PDP de este espectro. La validación se realizó usando el índice gamma con el umbral típico de aceptación clínica. Los resultados mostraron que la PDP del espectro en vacío tuvo mejor coincidencia que la PDP del espectro con aire (Pa = 100 %), respecto a la PDP medida (Pa = 97 %). Respecto a los PD, la introducción de aire mejoró el acuerdo en la zona de interés clínico, pero no lo suficiente como para alcanzar el porcentaje de aceptación. Se concluye que esta técnica no parece ser una buena alternativa para corregir las discrepancias en los bordes de campo entre el PD de un espectro reconstruido inversamente y la PD medida.

Palabras clave: *reconstrucción inversa, electrones, aire, índice gamma, perfil de dosis.*

1. INTRODUCTION

In radiotherapy, knowing the energy spectrum of the electron beam incident on the surface of the patient or phantom is important for the accurate calculation of the delivered dose [1-2]. In the clinic, the delivered dose is perhaps the most relevant factor for tumor control. However, as dose varies with depth and along the lateral axis of the incident plane, the percentage dose at depth (PDP) and the dose profile (DP) are used as parameters for dose adjustment to the tumor. Therefore, the PDP and PD are critically dependent on the shape of the energy spectrum [3].

Of the three existing methods to calculate the electron spectrum, the most accurate is the Monte Carlo Simulation of the accelerator head; the most realistic, the one using electron magnetic spectrometers; and the most practical and simple, the inverse reconstruction (IR) [1-2] [4]. The IR consists of deriving the spectrum from the solution of the Fredholm equation of the first type, previously simulating the monoenergetic PDP matrix, measuring the clinical PDP and calculating the dose of the contaminating photons [1, 3].

In previous work, electron spectra have been obtained with a clinical accuracy as high as more than 95 % of the simulated PDP points from reconstructed spectra within a gamma index of 1 %/1mm with respect to measured PDPs and 2 %/2mm with respect to measured PDs, for clinical electron beams of nominal energy between 9 and 15 MeV [1-2].

However, in these same works, in clinical beams of lower energy (6 MeV), the PD passage criterion should be relaxed up to 4 %/4mm to exceed 95 % clinical acceptance rate.

To improve accuracy in these beams, some authors have proposed considering corrections for angular dispersion, introducing air between the source and the phantom surface or an energy-dependent effective source-surface distance (ESD) [5- 6]. However, there are no works that have explored the latter two options. Therefore, in this study we aim to establish whether introducing air between the source and the phantom surface improves the agreement between the dose profile of a reconstructed electron spectrum of nominal energy 6 MeV and the dose profile of the clinical beam of the same energy from a Varian linear accelerator.

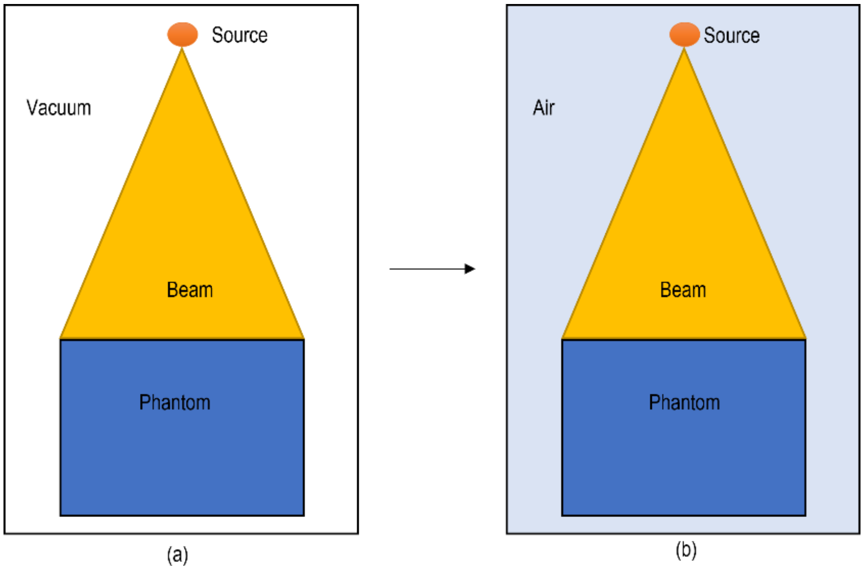


Figure 1. Simulation geometry of the electron beams to obtain the monoenergetic PDP and PDP reconstructed from the spectrum in previous work (a) and current work (b). Field size 10×10 cm2 at 100 cm source-surface distance. **Source:** author, 2023.

2. MATERIALS AND METHODS

To carry out this work, a PDP of 6 MeV was obtained from a Varían Clinac 21EX linear accelerator of the Muriaé Cancer Hospital (Brazil). The linear extrapolation method of the PDP was used to find the dose of the contaminating photons [7]. Then, the electron spectrum of the beam was calculated inversely, using generalized simulated annealing [8] and Tikhonov regularization [9].

These processes are prior to the objective of this work, it is suggested to consult previous articles where each of these processes has been described extensively [1-3] [10-11].

To achieve the objective, two changes were made with respect to previous works: i) the monoenergetic PDPs were simulated with the same geometry as in [1] but introducing air, instead of vacuum. That is, air material is added in the input file in the PENELOPE Monte Carlo code; ii) the same is done to obtain the simulated PDP from the reconstructed spectrum (Figure 1).

All PDPs (monoenergetic and simulated from the spectrum) were obtained using the PENELOPE code with a statistical uncertainty of 2% at the depth of the maximum range corresponding to 2×108 simulated particles.

To assess the agreement between measured and simulated PDP in vacuum and air, the American Association of Physicists in Medicine (AAPM) criteria (>95% within 2%/2mm of dose and distance difference for agreement, respectively) were considered [12].

3. RESULTS AND DISCUSSION

The 6 MeV electron beam energy spectra reconstructed from monoenergetic PDPs in vacuum and in air, in Fig. 1 show noticeable discrepancies in the peak and pre-peak region. The spectrum in air has a narrower peak than its vacuum counterpart (Figure 2), making it more energetic. The PDP simulated from the two spectra above show different results (Figure 3).

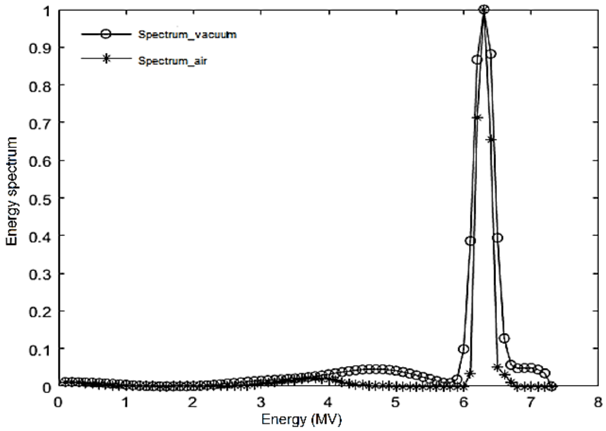


Figure 2. 6 MeV energy spectra obtained from PDPs in vacuum and air. **Source:** author, 2023.

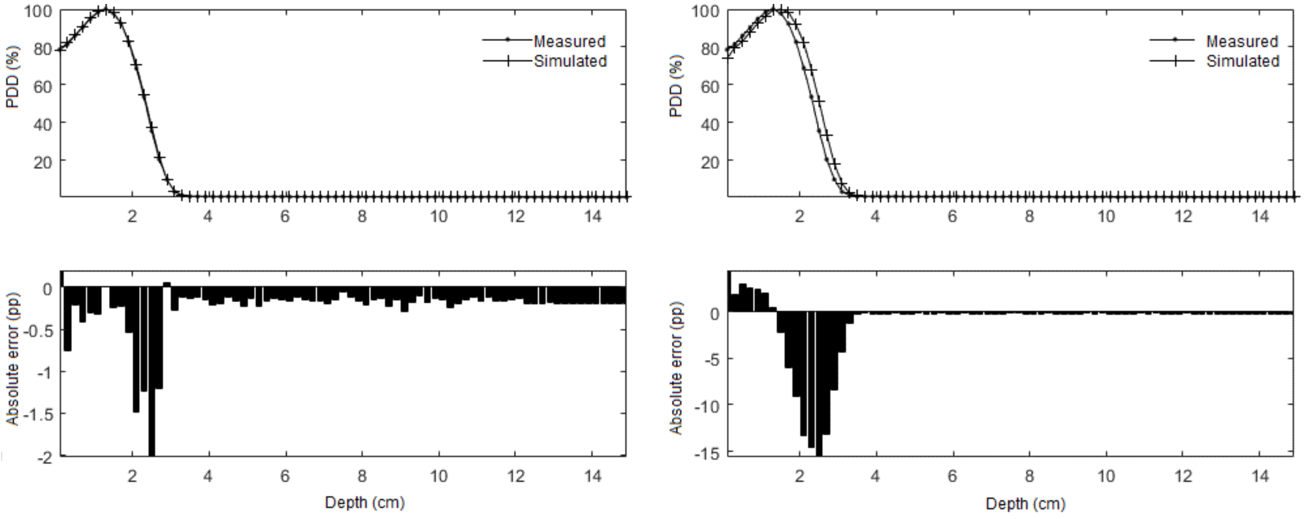
While the vacuum spectrum shows a 100% agreement of the gamma index (2 %/2mm), in the air spectrum the passage percentage drops to 100%, which is still acceptable. The greatest discrepancies are in the surface

As observed, the PDP of the vacuum spectrum more closely represents the measured PDP, indicating that this spectrum, under this indirect validation criterion, is close to the real one (not shown).

When observing the reconstructed dose profiles of the vacuum and air spectra, with respect to the measured dose profile, it is noted that the vacuum one presents serious discrepancies in the field edge region, while the air one improves in this region, worsening beyond the twilight zone, below the 20 % line (Figure. 4).

Indeed, for the PD passage percentage of the simulated spectrum in vacuum it is 78%, for that of the spectrum in air, 73%. However, when the analysis is restricted to the area of clinical interest (-6 cm to +6 cm, approx.), the air spectrum improves the coincidence up to 90 %. The vacuum spectrum reaches 83%.

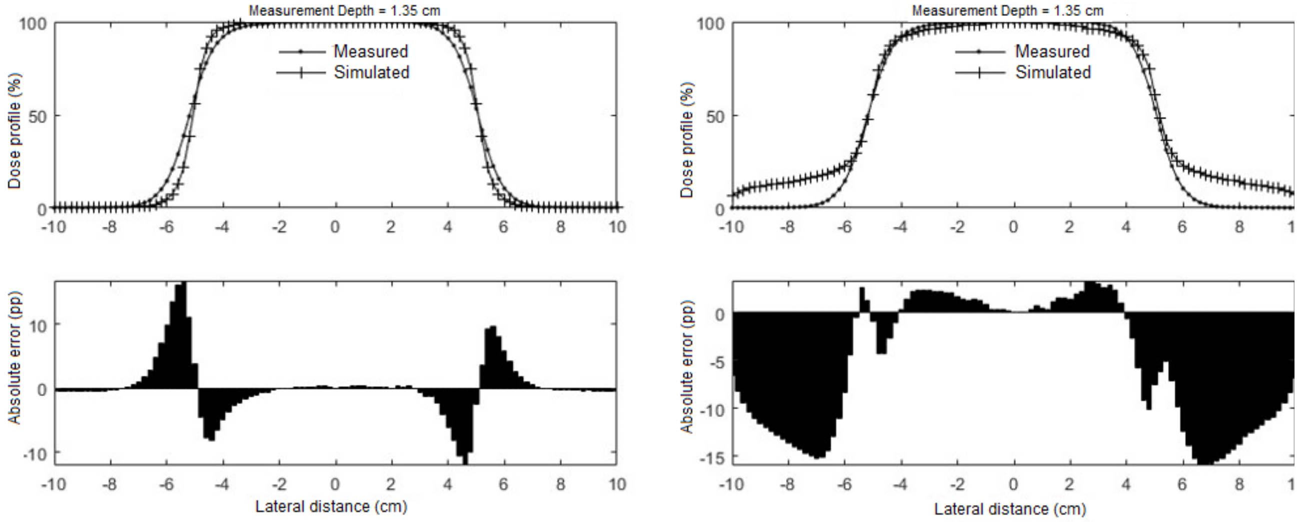
However, as their results in PDP coincidence improved, it would be worthwhile to explore the other alternative: changing the effective source-surface distance as a function of nominal energy.



(a)

(b)

Figure 3. Comparison of measured and simulated PDP in vacuum (a) and air (b). **Source:** author, 2023.



(a)

(b)

Figure 4. Comparison of measured and simulated PD in vacuum (a) and air (b). Measuring depth: 1.35 cm. **Source:** author, 2023.

4. CONCLUSIONS

The introduction of air between the radiation source and the phantom surface, while improving the agreement between the Monte Carlo simulated dose profile from an inversely reconstructed spectrum and the clinically measured dose profile for a 6 MeV electron beam, does not achieve the 95% clinical acceptance threshold of the 2%/2mm gamma index suggested by the American Association of Physicists in Medicine (AAPM). It is recommended that the effective source-surface distance method be explored.

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