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Evaluation of the heterogeneity corrections impact in lung stereotatic body radiation therapy

Avaliação do impacto das correções de heterogeneidade na radioterapia estereotáxica corpórea pulmonar

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Abstract

Stereotactic body radiation therapy (SBRT) refers to an emerging radiotherapy that is highly effective in controlling early primary and oligometastic cancers at locations throughout the abdominopelvic and thoracic cavities, and at spinal and paraspinal sites. Some protocols have been developed for this procedure. In the special cases of lung, there are protocols in use that consider heterogeneity corrections and others that do not make use of heterogeneity correction. In this work, we recalculated, considering the different tissue densities plans initially optimized without heterogeneity corrections to evaluate the dosimetric changes that occurs, for example, PTV (planning target volume) coverage, dose to isocenter and dose to critical structures, and we calculated gamma function between the dose plans originated in the two conditions. We also performed the superposition between the calculated gamma function with the respective CT slice in order to evaluate in what conditions occur the major differences between the conditions of calculus considered. The results showed that relevant variations occur between the two situations of calculus. With the superposition of the image relative to γ index and its respective CT slice, we could visualize where the greatest discrepancies occur. These data allow us to evaluate with more accuracy the doses delivered to the target and organs at risk and compare different protocols, independently of the use or non-use of heterogeneity corrections.

Keywords: lung, stereotactic body radiation therapy, conformal radiotherapy, computer-assisted image processing.

Resumo

A Radioterapia Estereotática Extra-Cranial (SBRT) refere-se à técnica de radioterapia emergente que é altamente efetiva no controle de tumores primários em estágio inicial e oligometastático localizados nas cavidades abdominais e torácicas, e em sítios espinhais e paraespinhais. Alguns protocolos têm sido desenvolvidos para esse procedimento. Nos casos especiais de pulmão, há protocolos que consideram as correções de heterogeneidade e outros que não o fazem. Neste trabalho, nós recalculamos, considerando as diferentes densidades do tecido, planos inicialmente otimizados sem correção de heterogeneidade, a fim de avaliar as mudanças dosimétricas que ocorrem como, por exemplo, cobertura do PTV (volume alvo), dose no isocentro e dose em órgãos de risco; foi ainda calculada a função gamma entre as duas condições de cálculo. Ainda, executamos a sobreposição do cálculo da função gamma com o respectivo corte tomográfico, para avaliar em quais condições ocorrem as maiores diferenças entre as duas situações de cálculo apresentadas. Os resultados mostraram que ocorrem variações relevantes entre as duas situações de cálculo. Com a sobreposição da imagem relativa à função gamma com seu respectivo corte tomográfico, conseguimos vusualizar as regiões em que ocorrem as maiores discrepâcias. Tais dados permitem avaliar com mais precisão a distribuição de dose no alvo e nos órgãos em risco, e comparar diferentes protocolos, independentemente do uso ou não uso das correções da heterogeneidade.

Palavras-chave: pulmão, radioterapia estereotáxica corpórea, radioterapia conformal, processamento de imagem assistida por computador.

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Introduction

Lung cancer remains the most frequent cause of cancer death in both men and women in developed countries[1]. Of the patients with bronchogenic carcinoma, 75% will be diagnosed with non-small cell lung cancer (NSCLC). Approximately 15-20% of NSCLC patients present early or localized disease. Although surgical resection of Stage I (Stage T1-T2N0) NSCLC is the classical treatment, some patients with early-stage NSCLC are unable to tolerate the rigors of surgery or the postoperative recovery period because of the lack of an adequate respiratory reserve, cardiac dysfunction, diabetes mellitus, vascular disease, general frailty or other morbidities[2]. In addition, promising clinical results of SBRT for early-stage lung cancer have been reported by several groups[3]. Nowadays, there are protocols that make special recommendations in all steps of the clinical procedure, immobilization, image acquisition, treatment planning target localization, delivery of the treatment, etc. However, the protocols do not make a unique recommendation about the use or not of the heterogeneity correction in the treatment planning, and it is known that dose calculation with and without tissue heterogeneity corrections have dramatic deviations for the treatment planning. The differences exist for the dose to the isocentric point and for the dose distributions, including target coverage and normal structure sparing. This is because the air-tissue interfaces present in the thorax, where the effects of transient electronic disequilibrium and increased lateral electron range in air will result in an important reduction in the central axis dose beyond the cavity and potentially an underdosage of the tumor. So, for an accurate calculus of dose distribution in a treatment planning, heterogeneity correction becomes extremely important, and dose-calculation algorithms which do not account for lateral electron scattering can yield incorrect results.

In order to evaluate accurately dose distributions, PTV coverage, critical structures sparing and conformity index in SBRT treatments plans originally optimized without heterogeneity corrections, and to be able to compare different SBRT protocols, we recalculated these plans with tissue density correction. Later, we calculated gamma function between two situations of calculus and we performed the superposition of the calculated gamma function with the respective CT slice, where we evaluated in what conditions occur the major differences between the plans.

Materials and methods

Unlike conventional radiotherapy, which is based on the delivery of a uniform prescription dose to the target volume, a paradigm of prescribing dose for SBRT is based on the following set of conditions: a limited volume of tissue, containing the gross tumor and its close vicinity, is targeted for treatment through exposure to a very high per fraction, and hotspots within the target are often deemed to be acceptable; the volume of normal tissue receiving high doses outside the target shoud be minimized to limit the risk of treatment toxicity. Thus, the gradient describing the dose fall-off outside the target should be sharp, which is accomplished by prescribing SBRT plans at low isodoses (e.g., 80% isodose) and with small or no margins for penumbra at target edge. Hence, treatment plans become complex and there are general metrics that must be analyzed, such as target coverage (D95, dose that covers 95% of the PTV; D99, dose that covers 99% of the PTV), prescription ICRU reference point, plan conformity (ratio of prescription isodose volume to PTV volume), dose fall-off outside the target (e.g., ratio of the volume of the 50% of prescription isodose curve to PTV volume) and doses to organs at risk. Ten plans from different protocols have been evaluated in the Oncentra Treatmet Planning (OTP). The original plan was calculated and optimized with pencil beam without heterogeneity corrections, 6 MV photon beam. Therefore, with the same monitor units (MU), the plan was recalculated with heterogeneity correction. The algorithm used here was Collapsed Cone. The Collapsed Cone algorithm is a volume-oriented algorithm that accounts also for lateral energy transport. It will, therefore, give a reasonable accurate description of the dose distributions in situations with marked inhomogeneities. It is based on precalculated point kernels that describe the deposition of energy from a photon interaction site as a function of direction and distance. The dose concept is to calculate the dose to the actual medium itself rather than to the Bragg-Gray water cavity[4]. In order to evaluate if the use of distinct algorithms would induce, we performed simulations in homogenous medium with the two algorithms, being the agreement between them about 0.5%.

To evaluate the dosimetric changes between the two situations of calculus, we analyzed dose to isocenter, D95, D99, conformity index (CI) and dose to critical structures. Nevertheless, the results of these parameters do not show the specific regions where these differences occur. To a better comprehension of the clinical implications that may arise due to the use or nonuse of heterogeneity correction, we calculated the γ index[5] between both dose distributions and we performed superposition of the image resulting from the gamma function and the respective CT slice.

Results

Figure 1 shows the isodode distribution with and without tissue density correction in a slice relative to the central PTV volume. With heterogeneity correction, occurred loss of PTV coverage by the prescription dose, while the 50% prescription isodose extended over the volume. The percentage of PTV volume receiving the prescribed dose decreased and the 50% prescription isodose volume, increased. Figure 2, PTV dose volume histogram, illustrates the loss of PTV coverage and more hotspots incidence.

It is illustrated the isocenter dose ratio, D95 ratio, D99 ratio from plans with and without tissue density corrections on Figures 3, 4 and 5, respectively. In general, the isocenter dose increases in plans with tissue density corrections, since

there is less attenuation in lung volumes. The isocenter dose difference ranged from 2.1 to 7.0% (mean, 5.5%; standard deviation, 1.4%). The D95 e D99 ratios show a tendency to PTV loss of coverage. The differences between D95 values for plans with and without corrections of tissue density corrections ranged from -15.9 to 3.0% (mean, -6.5 %; standard deviation, 11.7 %). The differences between D95 values for plans with and without heterogeneity corrections ranged from -17.8 to 5.8% (mean, -6.1%; standard deviation, 19.7%). The conformity index (CI), the ratio of the volume of the prescription isodose to that of the PTV, it's an important parameter to evaluate the quality of SBRT treatment planning. In the cases analyzed in this work, there were no significant changes in the CI values for the two situations of calculus. However, 1 of the 10 cases had a CI for density unit calculus of 1.26 and, with heterogeneity corrections, 0.4. With and without heterogeneity corrections, the CI values were within the tolerance of the respective requirements protocol.

For the critical structures, the percentage of the lung volume receiving ≥20 Gy was limited to be not >10%, and other constraints are listened in Table 1. Although the dose distributions change significantly with heterogeneity corrections, the constraints were still respected. The maximum dose to esophagus varied from -7 to 43%. The maximum dose to heart varied from -7 to 8%. The maximum spinal cord dose varied from -7 to 22%. The maximum dose to brachial plexus ranged from -11 to -5%, and the maximum dose to bronchus, from 10 to 12%. The average dose to these organs had small variations, within about 10%.

The metrics values analyzed give us useful information of the changes that happen between both situations of calculus, they do not refer to the specific sites where the changes occur. Figure 6 shows a schematic representation of the workflow applied to evaluate the specific locations

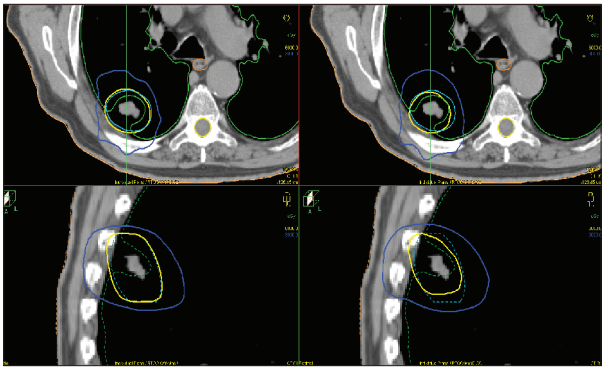

Figure 1. Isodose distributions with unit density (left) and with density corrections (right) in axial (upper) and sagital (lower) projections. Prescription and 50% prescription isodoses curves.

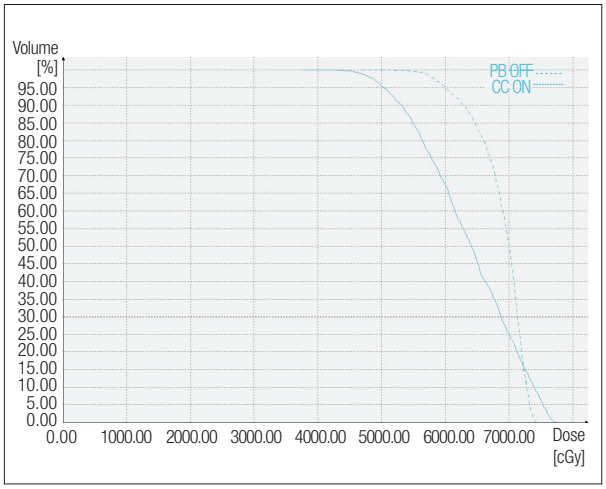

Figure 2. Dose-volume histograms for PTV coverage with unit density (dashed-line) and with density corrections (solid line).

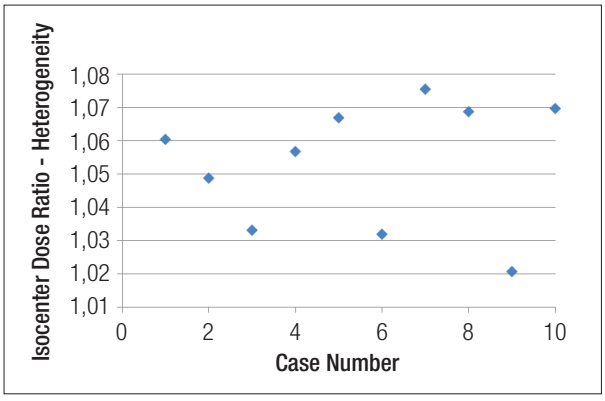

Figure 3. The isocenter dose ratio between plans calculated with and without density corrections.

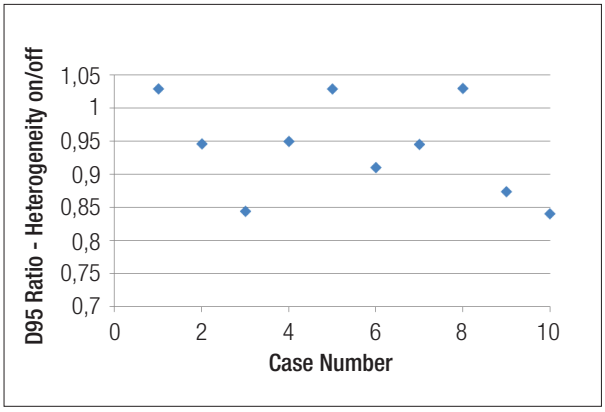

Figure 4. The D95 ratio between plans calculated with and without density corrections.

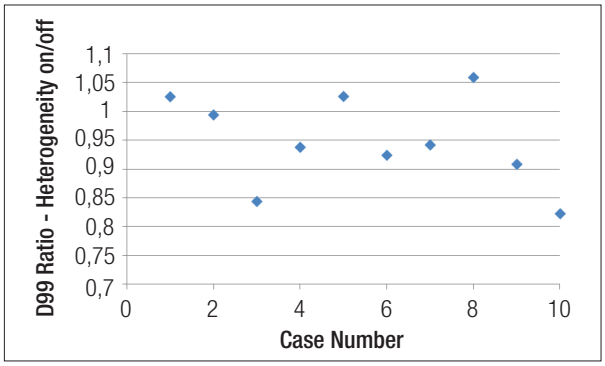

Figure 5. The D99 ratio between plans calculated with and without density corrections.

Table 1. Dose constraints for critical structures.

Organ	Max critical volume above threshold	Threshold dose (Gy)	Max point dose[a] (Gy)	End point (≥Grade3)
Spinal cord	<0.35 cc	18 (6 Gy/fx)	23.1 (7.7 Gy/fx)	Myelitis
Esophagus	<5 cc	17.7 (5.9 Gy/fx)	25.2 (8.4 Gy/fx)	Stenosis/fistula
Brachial plexus	<3 cc	20.4 (6.8 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Heart/pericardium	<15 cc	24 (8 Gy/fx)	30 (10 Gy/fx)	Pericarditis
Trachea and large bronchus	<4 cc	15 (5 Gy/fx)	30 (10 Gy/fx)	Stenosis/fistula

[a]"Point" defined as 0.035 cc or less.

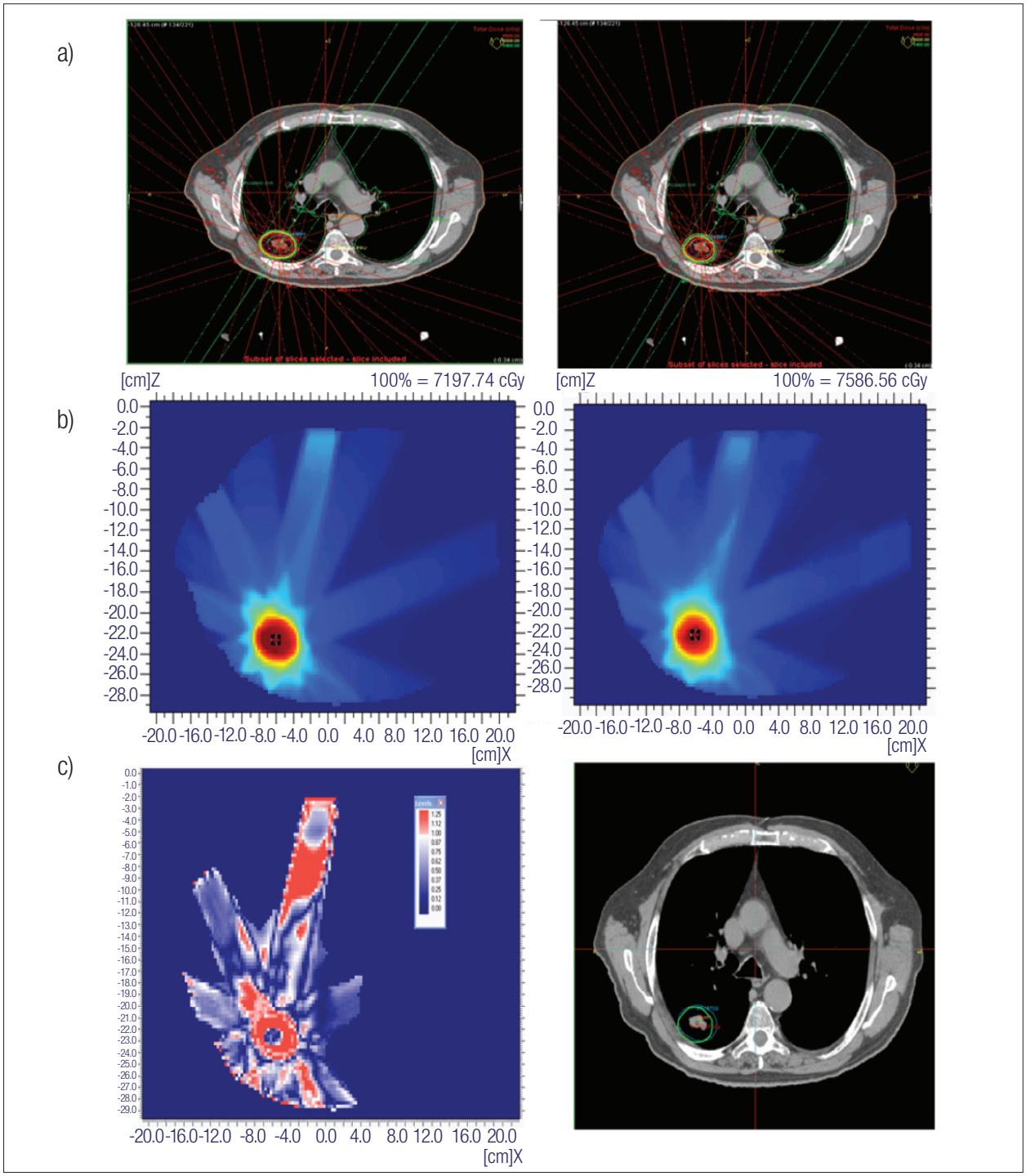

Figure 6. Schematic representation of the process to perform the image superposition between calculated γ index image and its respective slice CT. a) Tomographic slice and the isodose distribution in OTP. Left, isodoses curves originated from the non-corrected tissue density value calculus; right, isodoses curves originated from the density corrections calculus. b) RT DOSE exported to OmniPRO IMRT® workspace. c) Images to be superimposed: left, the calculated gamma function between the two RTDOSE in b); right, the respective CT slice.

where happen the prominent differences. From the calculated plans, calculated with and without heterogeneity corrections, the RTDOSE file were exported to the OmniPRO IMRT® workspace, in which the γ index was calculated. Hence, we ran the superposition of the resulting image from the calculated γ index with the respective CT slice.

The resulting images are shown in Figure 7. With the overlay of the resulting gamma function image with the corresponding CT slice, it's clear that the greatest differences occur in regions of tissue-air interface, due to non-electronic equilibrium, and in regions of low electron density (lung), due to the transient electronic disequilibrium and increased lateral electron range.

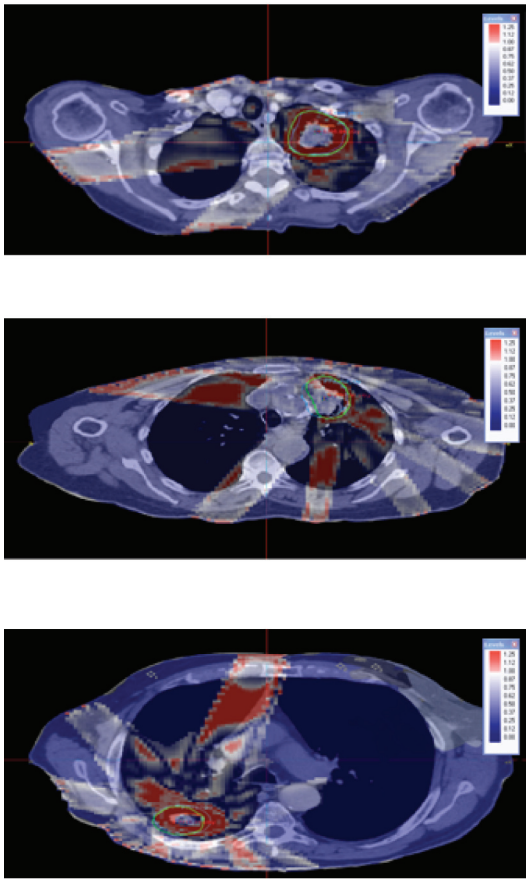

Figure 7. Images generated from the co-registration of the gamma function image with the corresponding CT slice.

Discussion

The results showed that important variations occur in the isodose curves generated with and without heterogeneity correction. There are significant loss of PTV volume coverage (in some cases, close to 20% of PTV loss of coverage) and, in general, percentual increase in dose received by the critical structures. It's important to keep in mind when look to these results that the plans were not reoptimized after calculated with heterogeneity corrections. However, with this analysis, we can evaluate dose delivered to the tumor site and critical structures with more accuracy. Still, current and newer protocols are being designed with the recommendations to use heterogeneity corrections in treatment planning calculus. A long as the use of heterogeneity corrections changes dramatically, the analysis carried out in this work enable dosimetric comparison between different protocols.

The superposition of the image resulted from the gamma function with the respective CT slice habilitate us to evaluate the specific location where occur the major differences between both calculus configurations. Hence, we may infer about the clinical implications of these differences.

Conclusion

The heterogeneity corrections affect significantly dose distributions. The evaluation ran in this work enable us to infer with more accuracy in dose delivered to critical structures and tumor volume, and evaluate the specific sites where the major discrepancies occur.

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