IMPACT ANALYSIS OF BEAM-HARDENING CT-ARTEFACTS IN RADIOTHERAPY PLANNING

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The methods of X-ray computed tomography being improved every year and we have a sufficient amount of methods and tools for high-quality visualization at that very moment. However, as practice shows, there are still low quality CTs (with the presence of strongly pronounced artifacts) in the developing countries. The quality of the scans is of great importance in radiotherapy planning. An incorrect mapping of the density distribution will distort isodoses calculation. In the present article, we will consider the impact magnitudes of the beam hardening artifacts on the radiotherapy planning.

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1. INTRODUCTION

With the development of computerized means of information processing, more and more voluminous and complex tasks are assigned to automated software in many areas of human activity. A striking example of such an area is radiation therapy, where automation of planning and technical implementation of treatment has allowed achieving significant results: three-dimensional planning replaced two-dimensional one, the emergence and development of IGRT, IMRT, RapidArc, VMAT and SRS techniques. Progressivity of automation is undeniable, but along with improving the methods of processing information, we have to rely increasingly on the accuracy and reliability of the results of such methods and tools. Thus, earlier (with manual RT planning) a medical physicist (or radiologist) when receiving a low-quality image or tomogram, could visually discard the obvious image artifacts (any systematic discrepancy between the CT numbers in the reconstructed image and the true attenuation coefficients of the object [1]) during planning and they did not significantly influence dose calculation in the target volume; nowadays, visualization data of the internal body structures being analyzed by software, usually not having the artifacts auto-correction function. As a result the calculation of isodoses can be made with gross dosimetric and geometric errors. Such artifacts can be classified by source of occurrence: on a hardware level, anatomical (arising from the peculiarities of the internal structures of the studied object) and conditioned by the human factor (incorrect research, whether it is a patient movement or a methodological error) [2]. Hardware faults and the human factor are problems eliminated by sufficient qualification of maintenance personnel and by organization of a QA system. Thus, features of the internal structures of the facility require the application of techniques for eliminating (or weakening) such artifacts [3]. One of the most common artifacts is the consequence of the beam hardening effect – an inhomogeneous weakening of the beam over the photon energy spectrum. It means that photons with lower energy in projections with a significant density will be absorbed in a much larger amount, which distorts the reconstructed image. A particular (and most problematic) case of such an effect are metal artifacts (Fig.1). Over the past few years, many methods of suppressing such artifacts have been proposed [4-7], but they can be useful in the primary tomogram processing only, i.e. at the stage of designing and creating software for CT scanners. A number of CT scanners (obsolete from this point of view, most of which are in developing countries) still have weak opportunities for suppressing such artifacts.

The authors of the article assume that correct planning can be performed only with a satisfactory quality tomogram (without contrast for diagnostic studies, without significant artifacts). However, in some cases the impossibility of performing revisualization during planning is still performed with the available image.

The purpose of this article is to consider the mechanism of influence on the process and the result of RT planning of increasing / lowering the density in the zone of interest on the reconstructed image due to the beam-hardening effect and metallic artifacts and to evaluate such influence.

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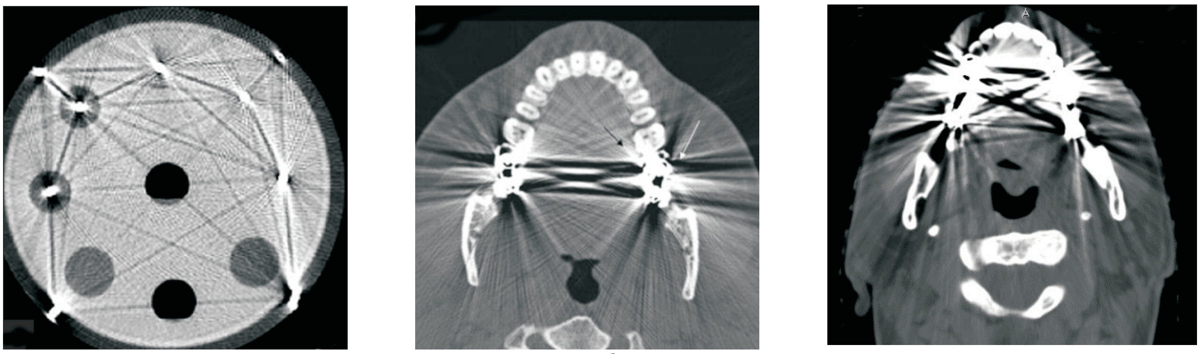


a b c

Fig.1. *Variations of the beam hardening effect in computed tomography: a – in phantom study; b and c – in head CT with teeth implants*

2. MATERIALS AND METHODS

As the purpose of this study is determination and evaluation the artifact's impact on planning, we need to compare the estimate of the treatment plan performed with a scans without artifacts, with an estimate of the plan with artifact ones. Phantoms being often used for such purposes [8,9], but to better approximate the real artefacts impact in this study, we use tomographic images of real patients. Even between two different visualizations of the same internal structures of the same patient made in different period of time, differences appear not only in the density distribution but also in the geometry of these structures. In order to correctly estimate the magnitude of the effect, the following research method is applied: we duplicate the scans without artifacts, add (with help of the planning system) the changes in the density values of some regions typical for the manifestation of beam-hardening artifacts in each localization considered. Then 3D conformal radiotherapy (CRT) plans were made (photon radiation 1.25 MeV (Co-60)) and 6 MeV (Varian Clinac 600C) using scans with added artifacts. After that we imported scans without artifacts into the plan and performed recalculation of isodoses with the same fields parameters. Also, one should pay attention to the localization choice for the studying of the artifacts influence, as comparing the estimates of treatment plans for different organs will not be correct. The question about the statistics of the areas of such artifacts greatest propagation remains open, but according to the preliminary collected data, the most frequently pronounced artifacts of this type occur during head and neck scanning (e.g., dental implants) [10]; such artifacts, with the same localization, presumably, will most heavily affect the result of planning with irradiating volume located in the oral cavity. To determine the value of the added density, statistical analysis of the average and maximum density values (in HU) in visually conspicuous areas of manifestation of artifacts are performed. It's made without taking into account the initial object of increased density. To avoid the registration of random calculated maxima, the maximum density values of the artifacts were taken in order to be the maximum of average density values of at least 9 nearby pixels with a spread of values not more than 20%. Results of analysis are shown in Table 1.

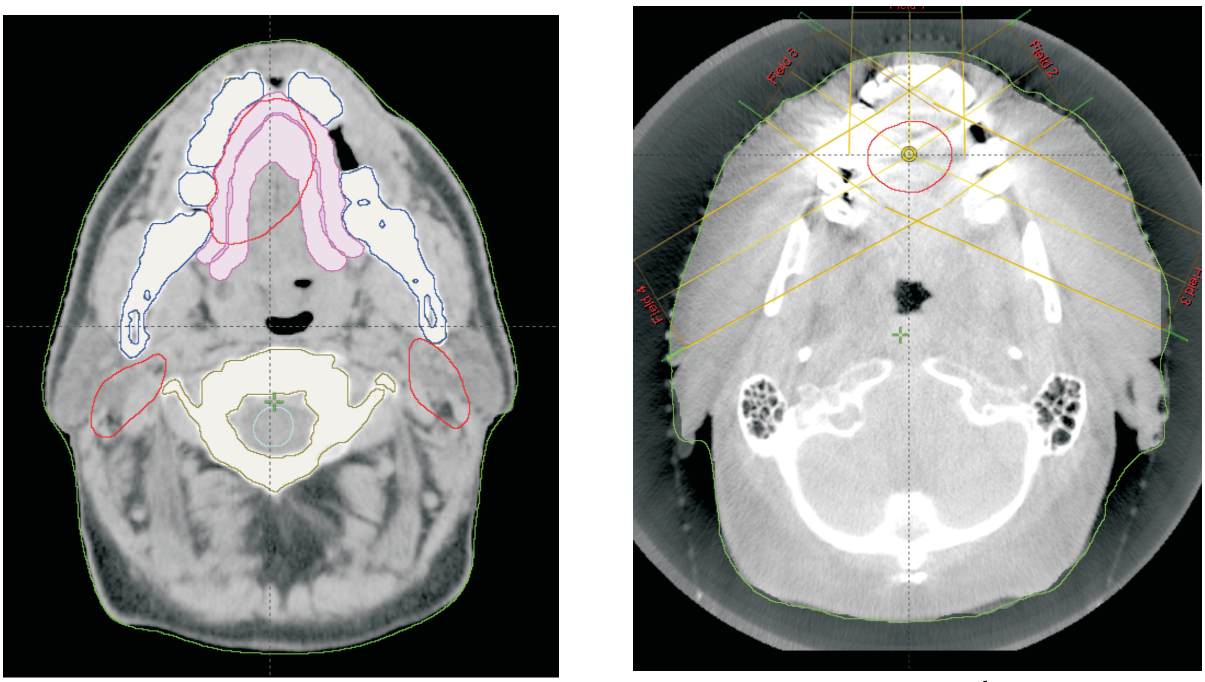
Table 1. *Analysis of average and maximum density values*

Effective (average) initial object density, HU	Average artifact density value, HU	Maximum artifact density value, HU	Number of analyzed tomograms
1000...1500	297	677	19
1500...3000	504	1119	16
3000...6000	987	2168	15
6000...9000	1659	3874	13

Given the weakening of the artifact appearance at a distance from the initial object, adding of the artifact is performed in two regions, one of which has the average density (according to the average density of the initial object for each tomogram) and the second with an increased density from average. Quality assessment method of the treatment plan is to select the dose-volume histogram (DVH). We compare DVH by average (effective), maximum and minimum doses for controlled volumes. Within the study, we will compare DVHs for treatment plans for tomograms with manifestations of the most common average values of the initial objects density (1000...1500 HU) for different energies, as well as DVH comparison for treatment plans compiled from tomograms with close to extreme initial density objects (6000...9000 HU).

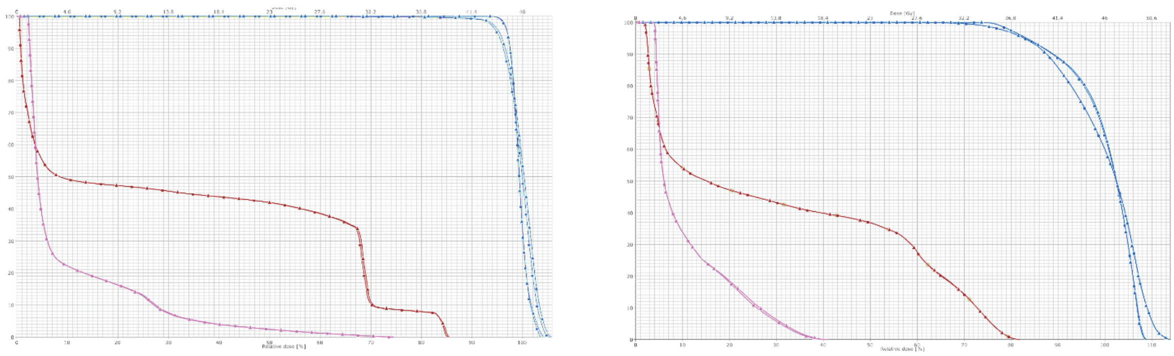
3. RESULTS

Treatment plans comparisons results for 16 patients with oral cavity tumors and delineated CTV are analyzed. 8 patients have got scans most commonly with a displayed average density of the initial object in the range 1000...1500 HU, then increased density areas of 500 HU were added before the treatment plan calculation and 300 HU also (Fig.2,a). Calculated plans and performed isodoses recalculation with fields parameters saving for 1.25 MeV and 6 MeV energies were transferred to the reference CT without added artifacts. A DVH comparison was made for plans with an artifact and without an artifact for of 6 MeV and 1.25 MeV energies (Figs.3,a and 3,b, respectively), in Tables 2.1, 2.2 the mean values of such comparisons are shown. In 4 cases, plans were made using scans with a high effective density of the initial object (6000...9000 HU), but without significant manifestations of the artifact. The study method was the same – adding objects with increased density (1500 and 1800 HU), making treatment plans for 1.25 MeV and 6 MeV photons, importing field parameters to the plan according to set of scans without an artifact, etc. DVHs comparison results are shown in Tables 2.3, 2.4. In 4 more cases, plans were made using low-quality tomograms with a high effective density of the initial object (6000...9000 HU) and with a pronounced artefact (Fig.2,b). The plans calculated using such tomograms for 1.25 MeV and 6 MeV were transferred to tomograms with corrected densities to 0 in the soft tissue zone, with the following saving field parameters. DVHs comparison results are shown in Tables 2.5, 2.6.



a b

Fig.2. *Internal structures in planning:*
a – added density distribution example; b – CT with high-density artefact example



a b

Fig.3. *DVH comparisons: a – for plans* 6 MeV *photons; b – for plans* 1.25 MeV *photons*

Table 2.1. *DVH compares 6 MeV*

Tomogram	CTV mean dose, %	CTV max dose, %	CTV min dose, %	brainstern mean dose	brainstern max dose	brainstern min dose
with artefact without artefact	100 99.6	105.3 105.6	93.7 93.6	9.6 9.6	74.5 74.6	2.3 2.3
with artefact without artefact	100 100.2	105.3 105.6	93.7 93.6	11.0 10.9	40.9 40.4	3.9 3.9
with artefact without artefact	100 102.8	107.2 106.6	92.7 93.3	3.5 3.9	12.6 14.5	0.9 0.9
with artefact without artefact	100 105.8	109.2 111.7	90.8 93.5	4.1 6.2	15.5 21.3	1.1 1.1
with artefact without artefact	100 102.7	107.1 106.8	93.3 93.9	5.2 5.8	11.2 12.1	1.2 1.2
with artefact without artefact	100 105.1	109.4 112.1	91.2 92.9	6.2 6.7	16.2 18.8	1.8 1.8

Tab. 2.2 DVH compares 1.25 MeV

Tab. 2.3 DVH compares 6 MeV extreme density

Tab. 2.4 DVH compares 1.25 MeV extreme density

Tab. 2.5 DVH compares 6 MeV extreme density

Tab. 2.6 DVH compares 1.25 MeV extreme density

4. CONCLUSIONS

According to DVH comparison results, for tomograms with the most common manifestations of metallic artifacts in aforementioned location, they introduce insignificant error (up to 0.4% for CTV mean dose) even with 1.25 MeV photons. However, extreme values of artifact density can lead to an error in the CTV mean dose of up to 3% for 6MeV and up to 5...6% for 1.25 MeV, which exceeds the accuracy of the dose release set by the IAEA. In the subsequent article authors are up to studying the statistics of the manifestations of metallic artifacts frequency in detail, and also to consider and compare possible methods for their suppression.

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АНАЛИЗ ВЛИЯНИЯ КТ-АРТЕФАКТОВ УЖЕСТОЧЕНИЯ ПУЧКА НА ПЛАНИРОВАНИЕ ЛУЧЕВОЙ ТЕРАПИИ

В. П. Старенький, И. А. Самофалов, Л. Л. Васильев, А. В. Трофимов

Несмотря на то, что методы рентгеновской компьютерной томографии совершенствуются из года в год, а также появляется значительное количество методов и средств для высококачественной визуализации, продолжают встречаться компьютерные томограммы низкого качества (с наличием ярко выраженных артефактов). Наиболее часто эта тенденция наблюдается в странах с неустойчивым экономическим развитием, где наряду с современным оборудованием для компьютерной томографии соседствует устаревшее поколение томографов. Качество визуализации имеет большое значение для планирования лучевой терапии – некорректное отображение распределения плотности исказит расчет изодоз. В данной статье мы рассмотрим величину влияния артефактов ужесточения пучка на планирование лучевой терапии.

АНАЛІЗ ВПЛИВУ КТ-АРТЕФАКТІВ ЗБІЛЬШЕННЯ ЖОРСТКОСТІ ПУЧКА НА ПЛАНУВАННЯ ПРОМЕНЕВОЇ ТЕРАПІЇ

В. П. Старенький, І. О. Самофалов, Л. Л. Васильєв, А. В. Трофімов

Незважаючи на те, що методи рентгенівської комп'ютерної томографії вдосконалюються із року в рік, а також з'являється багато методів і засобів для високоякісної візуалізації, продовжують зустрічатися комп'ютерні томограми низької якості (з наявністю яскраво виражених артефактів). Найбільш часто ця тенденція спостерігається в країнах з нестійким економічним розвитком, де поряд з сучасним обладнанням для комп'ютерної томографії є застаріле покоління томографів. Якість візуалізації має велике значення для планування променевої терапії – некоректне відображення розподілу густини спотворить розрахунок ізодоз. В даній статті ми розглянемо величину впливу артефактів збільшення жорсткості пучка на планування променевої терапії.