Original Article

Effect of Contrast Medium on Dose Distributions in Radiotherapy of Bone Tumor After Percutaneous Vertebroplasty : A Phantom Study

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Abstract

Palliative radiation therapy for bone tumors is widely implemented for variety of purposes. Among them, for treatment of vertebral compression fractures due to bone tumors, percutaneous vertebroplasty (PVP) and external beam radiation therapy after PVP are used. The contrast media mixed into bone cement are high atomic number materials. Moreover, dose calculations using Computed Tomography (CT) images may be inaccurate due to X-ray interactions and high density material employed in the commonly used Radiation Treatment Planning System (RTPS). The effect of contrast medium on dose distributions in radiotherapy of bone tumors after PVP is unknown. Toward this end, we investigated the depth dose in the phantom, which was configured to the water-equivalent solid phantom, and contrast medium was acquired by film measurement and calculation of the RTPS. As a result, very high dose enhancement occurred. Additionally, our dose calculation algorithm, which employed methods such as Monte Carlo, and installing information of object substances to the RTPS were required for accurate calculation of dose distribution. Such features are not included in commercially available RTPSs, and if materials of high atomic numbers, such as metal implants, were included in the radiation field, the hot spot may not be recognized in the RTPS. In the radiotherapy of bone tumors after PVP, we recommend the opposing portal irradiation than the single field irradiation to reduce dose enhancement due to the backscatter.

(Keywords : Bone tumor, Contrast medium, External beam radiation therapy, Monte Carlo method, Percutaneous vertebroplasty (PVP))

Introduction

The utility of palliative radiation therapy for bone tumor has been shown in several reports[1-5], and this treatment method has been used for vertebral compression fractures due to bone tumors, a treatment regimen known as percutaneous vertebroplasty (PVP)[6-8] that is followed by external beam radiation therapy. In PVP, the vertebral body is fixed via bone cement. To visualize treatment location using X-ray imaging and fluoroscopy, contrast medium is mixed into bone cement. Contrast media are considered as high atomic number materials. However, almost human tissues have similar characteristics to water regarding the effects of radiation. Thus, in the commercially used Radiation Treatment Planning System (RTPS), all materials in the body are assumed to be water for the generated dose calculations with heterogeneous correction. In dose

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calculations using Computed Tomography (CT) images, including high density materials, these calculations may be highly inaccurate due to X-ray interactions and misrepresentation of high density materials in the RTPS. Several reports[9-11] have evaluated dose distributions around metal implants such as metal dentures ; however, there has not been a study to assess the effect of contrast medium on dose distributions in radiotherapy of bone tumors after PVP. We therefore evaluated how contrast media affected measurements and dose calculations in the RTPS.

Methods

The 10 MV X-ray was used for the general radiation therapy of bone tumors, using the Clinac 21EX (Varian Medical Systems) linear accelerator (linac). The commercially available RTPS (Pinnacle^3 ver. 9.0, Philips) and the EGSnrc Monte Carlo (MC) code were used for calculations. Regarding EGSnrc, the BEAMnrc[12] code was used to simulate X-ray beams, and dose deposition was simulated with the DOSXYZnrc[13] code.

Verification of Beam Models

The Clinac 21EX linac models were created in the RTPSs. The beam models of Pinnacle and the EGSnrc codes were validated for open field in water. The field size was 10 cm x 10 cm at the isocenter, and the source surface distance (SSD) was 100 cm. Percentage depth dose (PDD) was acquired in 1 mm intervals by a mini-type ion chamber (IBA CC13) measurement device and the RTPS. The measured and calculated dose values were normalized with the dose at 5 cm depth. Additionally, the relative errors between the dose calculated and the measured dose were calculated at each depth.

Verification Using Contrast Medium

Measurements

The measurement geometry for verification is shown in Fig. 1. Tough Water Phantom (Kyoto-Kagaku), Neobalgin HD (Kaigen-Pharma Corporation), and EBT3 radiochromic film (ISP Corporation) were used as measurement devices. Neobalgin HD was a powdery contrast medium ($BaSO_4$, 98.6 g/100 g of products). The field size was 10 cm x 10 cm at the isocenter, and SSD was 92 cm. The high density regions were created to fill the cavity for inserting the parallel plane type ion chamber in the Tough Water Phantom with contrast medium (Fig. 2). The density of contrast medium was calculated by the weight of the contrast medium and the cavity volume. The films were inserted at depths of 3.0, 4.0, 5.0, 5.5, 6.0, 6.5, 6.8, 7.1, 7.4, 7.6, 7.8, 8.0, 9.4, 9.6, 9.8, 10.0, 10.2, 10.5, 11.0, 11.5, 12.5, 14.0, and 16.0 cm to acquire depth doses. The measured dose values were normalized to the dose at 5 cm.

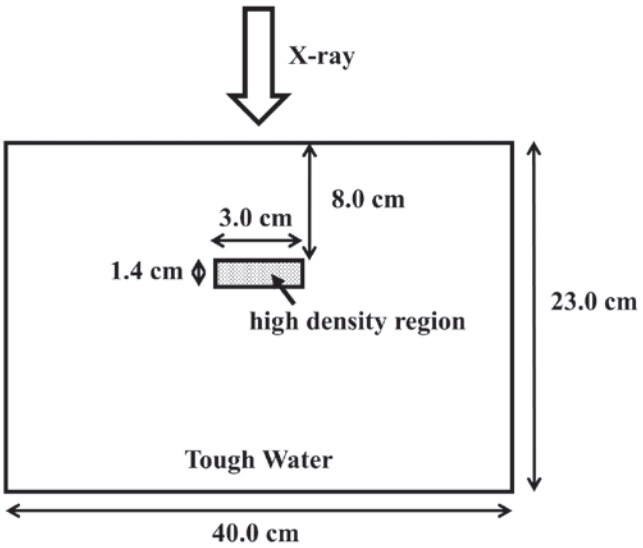

Figure 1 : Measurement geometry. Tough Water Phantom and Neobalgin HD (a powdery contrast medium) were used. The field size was 10 cm x 10 cm at the isocenter, and SSD was 92 cm.

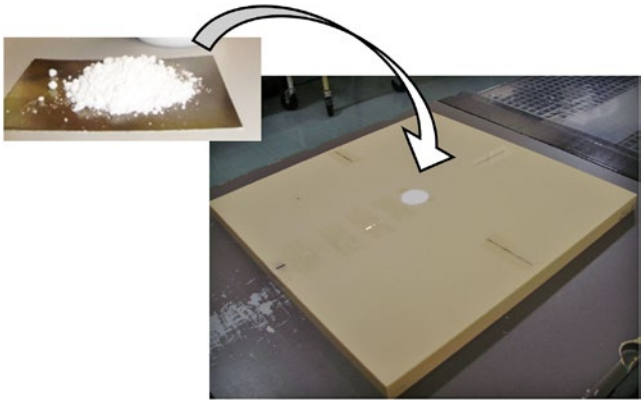

Figure 2 : Creation of the high density region. The high density regions were created to fill the cavity for inserting the parallel plane type ion chamber in the Tough Water Phantom with contrast medium.

Calculations

The virtual phantoms, which had the same geometrical measurement, were created. In the dose calculation with heterogeneous correction of the Pinnacle, all body materials were assumed to be water. Thus, the 2.64 g/cm^3 density value (reflective of $BaSO_4$ and was calculated from the method outlined in 2.2.1.) was assigned to the high density region, and the 1.00 g/cm^3 density value (reflective of water) was assigned to parts excluding the high density region. Collapsed Cone Convolution[14], with heterogeneous correction, was used for the dose calculation algorithm. In the EGSnrc code, any substance could be selected as a phantom material. In the first MC simulation, $BaSO_4$ (density : 2.64 g/cm^3) was selected as the material of high density region, and the parts excluding the high density

region were defined as water (density : 1.00 g/cm^3). In the second MC simulation, water (density : 2.64 g/cm^3) was selected as the material of high density region, and the parts excluding the high density region were defined as water (density : 1.00 g/cm^3). Statistical errors were < 1%. The depth scaling factor[15] of the Tough Water Phantom was approximately 1.0, and thus, the density 1.0 was assigned to the parts of Tough Water Phantom. The relative errors between the dose calculated and the measured dose were calculated at each depth.

Results

Verification of Beam Models

Figure 3 shows the PDD calculated with each RTPS and measured with use of the ion chamber in water. With the exception of the build-up region, all relative errors were within 3%.

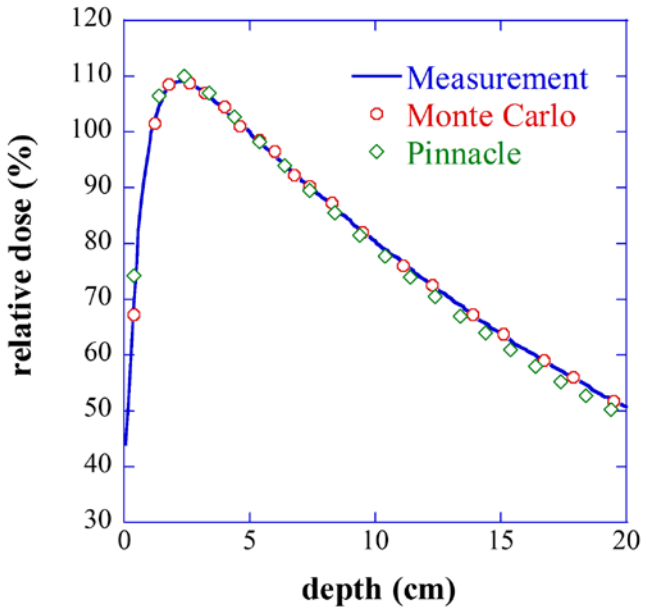

Figure 3 : PDD calculated with each RTPS and measured with use of the ion chamber in water. With the exception of the build-up region, all relative errors were within 3%.

Verification Using Contrast Medium

Figure 4 shows the PDD calculated with each RTPS and measured with use of EBT3 in the heterogeneous phantom. In the film measurement and MC simulation using $BaSO_4$, the very high dose enhancement occurred proximal to the high density region. However, in the Pinnacle and MC simulation using water, dose enhancements were not found.

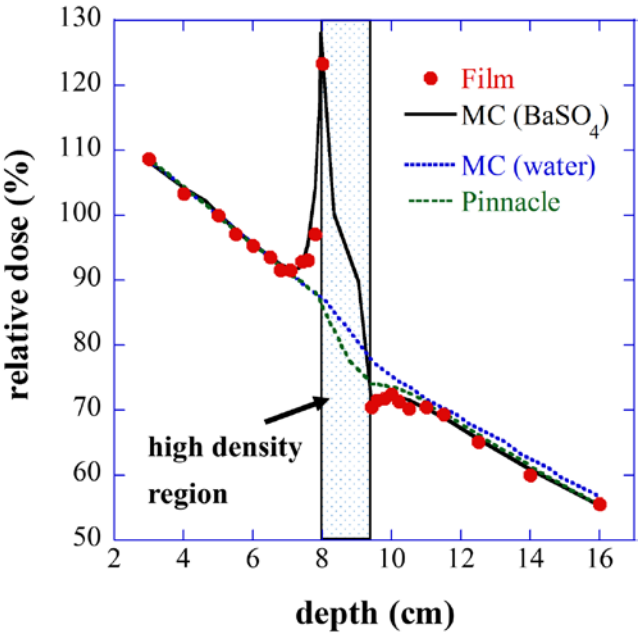

Figure 4 : PDD calculated with each RTPS and measured with the use of EBT3 in a heterogeneous phantom. In the film measurement and MC simulation using $BaSO_4$, the very high dose enhancement occurred proximal to the high density region. However, in the Pinnacle and MC simulation using water, dose enhancements were not found.

Discussion

As per the verification of beam models results, dose calculation of each RTPS and measurement agreed with those obtained at all depths after the depth dose maximum. This indicated that the X-ray beam models used in the RTPSs were accurate. In the build-up region, >3% differences between calculations and measurements were found. The mini type ion chamber was not suitable for the dose measurements in the build-up region because the uncertainty of measurement was large[16]. However, the mini type ion chamber was suitable for the depth dose measurements after the depth dose maximum, and thus disagreements in the build-up region may not have influenced the outcomes of this study.

Via investigating field measurements using contrast medium, very high dose enhancement occurred proximally. The backscatter dose from the contrast medium may be the primary cause[9]. For the Pinnacle, the dose enhancement due to backscatter from high atomic number materials was not reproduced, and a maximum -29.4% difference between calculations and measurements was found. Similarly, this phenomenon was not reproduced for the second MC simulation (high density region = 2.64 g/cm^3 water), and a maximum -28.2% difference between calculations and measurements was found. The MC method was used as the dose calculation algorithm, which could reproduce physical

phenomenon accurately, and the potential dose calculation accuracy was higher than that of the superposition in the heterogeneous regions. However, density as well as the information of the object substances was required to reproduce the dose enhancement due the backscatter. Therefore, the dose calculation algorithm and installing the information of the object substances to the RTPSs were both required to accurately calculate dose distribution around high atomic number materials. Such features are not found in commercially available RTPSs. Thus, if high atomic number materials such as metal implants were included in the radiation field, the occurrence of a hot spot would not be detected in the RTPSs. The dose enhancement due to backscatter was reproduced for the first MC simulation (high density region = 2.64 g/cm^3 $BaSO_4$), however, the difference between measurement dose and calculated dose was found proximal to the high density region. This might be due to difference between the actual contrast medium and virtual contrast medium. Additionally, increasing the uncertainty of the measurement and calculation due to the large dose gradient and the huge changes of the radiation energy spectrum near the contrast medium might also be a cause. For the acquisition of accurate dose distributions proximally to the high density region by the RTPS, not only were acquisition methods required to accurately assess material and shape of the object metal implants but also methods for creating a more accurate beam model were required.

To the best of our knowledge, there has not been a study dissecting the effect of contrast medium on dose distributions in radiotherapy of bone tumors after PVP nor dose evaluation around high atomic number materials. Glean from our work, opposing portal irradiation may be more useful than the single field irradiation method to reduce the effects of dose enhancement due to backscatter. Additionally, careful consideration is warranted if contrast medium and the spinal cord are very close to each other. Further investigations are necessary to evaluate the dose calculation accuracy of the RTPS via clinical CT images as well as assess dose measurements using phantoms that have the shapes of spines.

Conclusions

In this study, we evaluated the effect of contrast medium on dose distributions in radiotherapy of bone tumors after PVP. In summary, we clarified that a very high dose enhancement occurred proximal to the contrast medium. Additionally, the dose calculation algorithm used could accurately calculate dose distribution around high atomic number materials. We recommend that for radiotherapy of bone tumors after PVP, opposing portal irradiation is a viable and better option to minimize the effects of dose enhancement due to backscatter, with special consideration regarding contrast medium in proximity to the spinal cord.

Declaration of interest

The authors have no conflict of interest to declare.

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経皮的椎体形成術に使用される骨セメントに混入された造影剤が外部放射線治療における線量分布に与える影響

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要　約

骨腫瘍に対する緩和放射線治療は様々な目的で広く利用されている。骨腫瘍による椎体の圧迫骨折に対する治療法として経皮的椎体形成術を実施した患者が，その後放射線治療を受ける場合がある。経皮的椎体形成術で用いられる骨セメントには，X線撮影や透視で視認できるように高原子番号物質である造影剤が混入されている。人体組織のほとんどは放射線に対して水に近い特性を持っているため，現在市販されている治療計画装置の多くは体内の物質をすべて水と仮定し，密度もしくは電子密度を変化させることで不均質計算を行っている。しかし，経皮的椎体形成術を受けた患者の外部放射線治療において，造影剤の線量分布への影響を評価した報告はない。そこで我々は，フィルムによる実測，モンテカルロシミュレーション，および市販されている治療計画装置であるPinnacleで造影剤を含むファントム中の深部線量を取得することでその影響を評価した。結果より，造影剤近傍では大きな線量増大が生じることが明らかになった。さらに，その現象を治療計画装置で再現するためにはモンテカルロ法のような物理現象を正確に再現できる計算アルゴリズムと，該当物質の情報を治療計画装置に登録する必要があることがわかった。市販されている多くの治療計画装置ではこれらの機能を有していないため，高原子番号物質を照射野内に含む場合，治療計画装置では確認できないホットスポットが生じている可能性がある。この影響を軽減するために，経皮的椎体形成術後の骨腫瘍に対する外部放射線治療においては後方一門照射より対向二門照射の方が有用であると考えられる。
（キーワード：骨腫瘍，造影剤，外部放射線治療，モンテカルロ法，経皮的椎体形成術）

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