一般セッション | VII. 保健物理と環境科学：保健物理と環境科学

2021年3月18日(木) 15:45 ~ 17:15 | M会場 Zoomルーム13

[2M04-08] 線量評価

座長：砂川 武義 (福井工大)

15:45 ~ 16:00

[2M04] Prediction of the position of external markers on the chest and abdomen using a recurrent neural network trained with real-time recurrent learning for accurate and safe lung cancer radiotherapy

*Michel Pohl[1], Mitsuru Uesaka[1], Kazuyuki Demachi[1], Ritu Bhusal Chhatkuli[2] (1. UTokyo, 2. QST)

16:00 ~ 16:15

[2M05] Study of Local Heating in Combination Treatment of Hyperthermia with Radiation Therapy for Breast Cancer Treatment

*Edmond Chen[1], Aditya Rakhmadi[2], Kazuyuki Saito[2], Youichiro Wada[1], Mitsuru Uesaka[1] (1. UTokyo, 2. Chiba Univ.)

16:15 ~ 16:30

[2M06] ICRP2007年勧告に基づく内部被ばく線量評価コードの開発

コードの全体概要

*高橋 史明[1]、真辺 健太郎[1]、田窪 一也[2]、佐藤 薫[1] (1. 原子力機構、2. ヴィジブルインフォメーションセンター)

16:30 ~ 16:45

[2M07] 体格の異なる成人日本人ファントムを用いた中性子外部照射に対する臓器線量評価

*佐藤 薫[1]、佐藤 大樹[1]、高橋 史明[1]、古田 琢哉[1] (1. 原子力機構)

16:45 ~ 17:00

[2M08] Evaluation of internal exposure effect in consideration of internal activation during boron neutron capture therapy

*Ryosuke Narita[1], Tatsuhiko Sato[2], Hiroki Tanaka[1], Takushi Takata[1], Yoshinori Sakurai[1] (1. Kyoto Univ., 2. JAEA)

17:00 ~ 17:15

座長持ち時間

Prediction of the position of external markers on the chest and abdomen using a recurrent neural network trained with real-time recurrent learning for accurate and safe lung cancer radiotherapy

*Michel Pohl[1], Mitsuru Uesaka[1], Kazuyuki Demachi[1] and Ritu Bhusal Chhatkuli[2]
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During lung cancer radiotherapy, targeting the tumor with the treatment beam is difficult due to patient breathing motion. In this work, we evaluate the capabilities of recurrent neural networks trained with real-time recurrent learning to predict the position of external markers on the chest and abdomen to compensate for the radiotherapy system latency.

Keywords : Lung cancer radiotherapy, latency compensation, recurrent neural network, real-time recurrent learning, external markers

1. Introduction

During the treatment of lung cancer with radiotherapy, positioning the X-ray beam correctly to minimize damage to healthy tissues is difficult because of the tumor motion due to breathing. Furthermore, the treatment system latency leads to inaccuracies in the beam delivery, which results in turn in unwanted damage to the tumor surrounding tissues. Therefore, predicting the position of tracked surrogates such as external markers is necessary.

2. Materials and Method

In the proposed study, we use observation records of the three-dimensional position of external markers on the chest and abdomen of three healthy males, which constitute in total 9 time-series sequences [1]. These were acquired using an infrared stereo camera with a frequency of 10Hz. The motion amplitude of the markers ranged from 17mm to 45mm in the antero-posterior direction, and from 6mm to 40mm in the superior-inferior direction. We split each series into a 60s training and development set, and the remaining test set. Prediction is performed using a recurrent neural network (RNN) trained with real-time recurrent learning (RTRL) and gradient clipping [2], the least mean-squares (LMS) algorithm, and multivariate linear regression, for the horizon value h=2s.

3. Results and Discussion

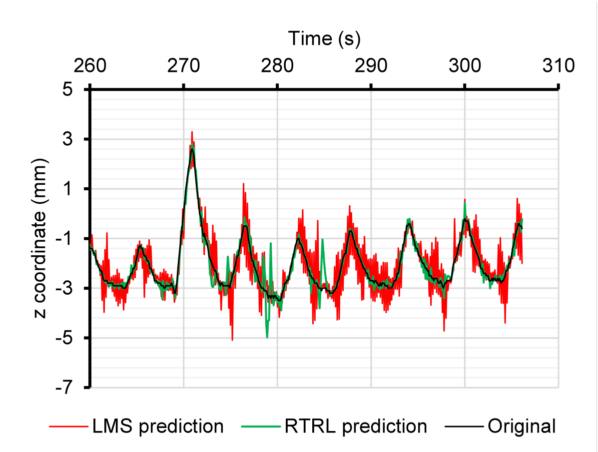

Fig. 1. Prediction of the z coordinate (spine axis) of marker 3 in sequence 9 (normal breathing) between t=260s and t=306.1s with the RNN and the LMS algorithm

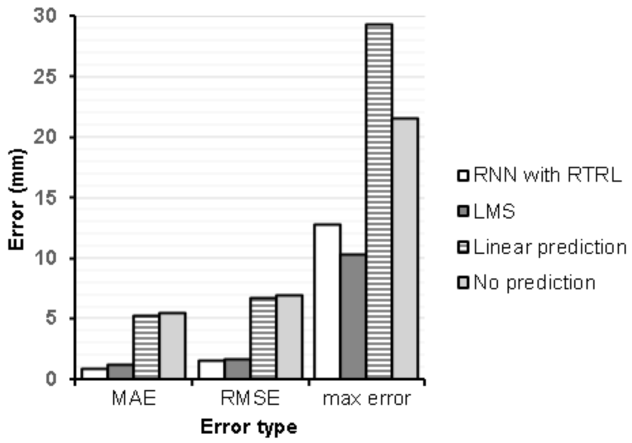

Fig. 2. Comparison of the MAE, RMSE and maximum forecast error for 4 different algorithms, averaged over the 9 breathing sequences.

When performing prediction with the RNN, we found a mean absolute error (MAE) of 0.9mm, a root-mean-square error (RMSE) of 1.6mm, and a maximum error of 12.7mm of the test set. These errors are lower than with the other methods considered, except the LMS method that has a corresponding maximum error equal to 10.2mm.

4. Summary

RNNs trained with RTRL are efficient at predicting breathing signals such as the position of external markers for latency compensation in lung cancer radiotherapy. RNNs indeed benefit from non-linear data processing and the RTRL learning method enables real-time adaptation to the predicted signal.

References

[1] T. Krilavicius, I. Zliobaite, A. Vidugiriene, H. Simonavicius and L. Jarusevicius. (2015). Predicting respiratory motion for real-time tumour tracking in radiotherapy. Arxiv. http://arxiv.org/abs/1508.00749

[2] Haykin, Simon. Neural Networks and Learning Machines, 3/E. Pearson Education India, 2010.

Study of Local Heating in Combination Treatment of Hyperthermia with Radiation Therapy for Breast Cancer Treatment

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[1]Univ. Of Tokyo, [2]Chiba Univ.

Abstract: Hyperthermia increases the temperature in the tissue, making targeted cells more sensitive to following treatments such as radiation therapy. The local effect in the combination of hyperthermia and radiation treatment in breast cancer therapy has been studied by comparing gene expression levels in cells receiving different treatment but contained in the same environment.

Keywords: hyperthermia, radiation therapy, microwave antenna, gene analysis, breast cancer

1. Introduction

The damages induced by radiation therapy on tumor cells can be increased when combined with hyperthermia treatment. The mechanism behind this sensitization effect is still unknown and has to be investigated to develop the combination therapy modality. Previously obtained results have shown surprising behavior in gene expression levels depending on the applied treatment. These results might have been affected by environmental conditions at which genes are highly sensitive to.

2. Method

To study local effects in the combination of hyperthermia and radiation therapy while limiting the effects of the environment, the experiment was designed to have a single petri dish contain cells undergoing different treatments. By heating the center of the petri dish with a microwave antenna, a temperature gradient is created thanks to the ambient cooling effects. The center of the petri dish undergoes hyperthermia treatment while the outer part is not heated.

The microwave antenna was designed using CST 2020 and studied through simulations. The temperature in the petri dish was obtained by using temperature measurements and interpolation methods with Python code. After collecting the cells, gene expression levels were studied after extraction of RNA, synthesis of cDNA and use of RT-qPCR.

3. Results and Conclusion

Differences in gene expression levels are observed in the same petri dish. Since the cells are subject to the same environment, these differences are due to the difference in treatment modality. Increases and decreases in gene expression levels are observed depending on the studied gene and give a better understanding of the underlying mechanisms in the combination of hyperthermia and radiation therapy for breast cancer.

References

[1] O. B. Debnath, et al., "Design of invasive and non-invasive antennas for the combination of microwave-hyperthermia with radiation therapy," *2015 IEEE MTT-S 2015 International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO),* Taipei, 2015, pp. 71-72, doi: 10.1109/IMWS-BIO.2015.7303782.

[2] Debnath, Oiendrila B, et al. "Interstitial Hyperthermia in Combination with Radiation Brachytherapy for Treatment of Breast Tumor." Thermal Medicine, vol. 33, no. 2, 2017, pp. 53–62., doi:10.3191/thermalmed.33.53.

ICRP 2007年勧告に基づく内部被ばく線量評価コードの開発：コードの全体概要

Development of internal-dosimetry code based on the ICRP 2007 recommendations: Overview of the code

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原子力機構では、国際放射線防護委員会(ICRP)の 2007 年勧告に対応した内部被ばく線量評価コードの開発を進めている。本発表では、昨年度までに開発したプロトタイプ(β版)の改良とその検証、さらに開発コードの今後の活用策を報告する。

キーワード：内部被ばく、線量評価，国際放射線防護委員会，2007 年勧告、線量係数，モニタリング

1. 緒言

原子力規制委員会からの受託事業により、原子力機構では平成 29 年度からの 4 ヶ年計画で、ICRP 2007 年勧告に対応するための国内の防護基準値の見直しや、モニタリングに基づく内部被ばく線量評価で技術的基盤となるコードの開発を進めてきた。昨年度までに、基本となる 2 つの計算機能を備えたコードのプロトタイプ(β 版)を開発した。今年度は、専門家より β 版に対する操作性や機能に関する意見を聴取する他、新しく公開された線量評価モデルを調査し、これらの結果を反映させてコードの開発や検証を進めた。

2. コードの開発及び検証

開発したコード β 版は、放射性核種 1 Bq 摂取あたりの線量(Sv)を与える線量係数(Sv/Bq)を計算する機能(線量係数計算機能)、モニタリング値から核種摂取量を推定する機能(核種摂取量推定機能)を備えている。このうち、核種摂取量推定機能は種々の摂取条件での適用が想定されるため、内部被ばく線量評価やモニタリングの知識や経験を有する機関の専門家より、操作性の向上等を図るための意見を聴取した。その結果を受け、グラフィカルユーザーインターフェイス(GUI)の標記を一部変更する他、摂取日をカレンダーで選択する機能等を追加することとした。また、利用者の専門知識に応じて、コードの機能を一部制限することとした。

一方、線量係数計算機能は 2007 年勧告の国内規制への取り入れに伴う内部被ばく防護基準値の見直しにおいて、ICRP が提示する新しい実効線量係数が基本となるモデルやデータ等に基づいて正確に導出されていることを独自に検証する目的で開発している。昨年度は、β 版により ICRP Publ. 134 及び ICRP Publ. 137 で公開されていた 27 元素に含まれる核種について、職業被ばくに対する実効線量係数を正確に導出することを検証していた。今年度は、令和 2 年 1 月に公開された ICRP Publ. 141 に含まれるランタノイド及びアクチノイド元素の職業被ばくに関する全身体内動態モデルを実装し、実効線量係数の導出に関する検証を進めた。

3. コードの活用策

開発したコードは、ICRP2007 年勧告の取入れに伴う内部被ばく防護基準値の見直しにおいて、ICRP が数値を公開していない半減期 10 分未満の核種の実効線量係数の導出、ICRP が今後公開する予定の線量評価モデルへも対応可能であり、有益な技術基盤となる。また、放射性核種を摂取した事態が生じた際、関係機関における内部被ばく線量評価での活用も期待できる。

本件は、原子力規制委員会「令和 2 年度放射線安全規制研究戦略的推進事業費(内部被ばく線量評価コードの開発に関する研究)事業」により得られた成果の一部である。

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[1]JAEA, [2]V.I.C.

体格の異なる成人日本人ファントムを用いた中性子外部照射に対する臓器線量評価

Evaluation of organ doses for external neutron irradiation by using adult Japanese phantoms with various body sizes

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[1]原子力機構

放射線防護分野では、欧米人の標準体格を持つ国際放射線防護委員会（ICRP）ファントムを用いて線量評価する。一方、成人日本人の体格は欧米人よりも小柄で、その中で変動幅も有する。本研究では、様々な日本人体格を模擬した男女ファントムを用いて、体格変動が中性子外部被ばく線量に及ぼす影響を解析した。

キーワード：成人日本人、臓器線量、体格変動、ファントム、中性子外部照射

1. はじめに　ICRP2007 年勧告では、放射線防護を目的とした線量評価において基礎となる臓器吸収線量（以下、臓器線量）の計算には、欧米人の標準体格を持つ ICRP ファントム（男性：RCP-AM、女性：RCP-AF）を用いることが明示された。一方、成人日本人の体格は欧米人よりも全般的に小柄であり、かつ変動幅を持つ。そのため、RCP-AM 及び RCP-AF で算出された臓器線量を国内の放射線防護に係る基準の策定や計画立案に適用する場合、日本人の体格とその変動幅の考慮が重要となる。これまでに発表者らは、光子外部照射に対して、成人日本人の体格やその変動を考慮した線量評価を行った[1]。本発表では、光子と同様に透過性の高い中性子の外部照射について、体格変動が臓器線量に及ぼす影響を評価した結果を報告する。

2. 方法　外部被ばくによる臓器線量に対しては、人体の組織厚が決定因子になることを考慮して、成人日本人の平均的体格を持つファントム JM-103（男性）及び JF-103（女性）の身長を一定にした条件の下、胸囲、腹囲、臀囲等の周囲長について、平均値から標準偏差（σ）のステップで変化させた DJM（男性）及び DJF（女性）を作成した。本発表では、周囲長の違いに応じて、DJMnσ 及び DJFnσ（n = −2、+2、+5）と表現する。ICRP が定義する理想的な 6 種類のジオメトリで、1.0×10^{-9} から 1.0×10^{4}MeV の 68 点の単色中性子をファントムに照射した条件で、粒子重イオン計算コード PHITS 3.20 を用いて臓器線量を計算した。なお、20MeV 以下の中性子による臓器への沈着エネルギー評価には、Kerma 近似を用いた。ここで、発生するヒストリー数は、臓器への沈着エネルギーにおける統計誤差が 5%以下となるように設定した。

3. 結果及び考察　図 1 に 3MeV 中性子を回転照射した際の成人日本人ファントムの結腸線量を、RCP-AM 及び RCP-AF による値[2]と比較した結果を例として示す。成人日本人ファントムの結腸線量は、組織厚と密接に関連する体格が大きくなる程減少する傾向を示した。減少が最も大きかった DJM+5σ の結腸線量と RCP-AM の値との差は約−37%であった。一方、多くの日本人が含まれると想定される、胴体の周囲長について平均値±2σ の範囲の体格を模擬した成人日本人男女の結腸線量は、ICRP ファントムの結果と±20%の範囲で一致した。

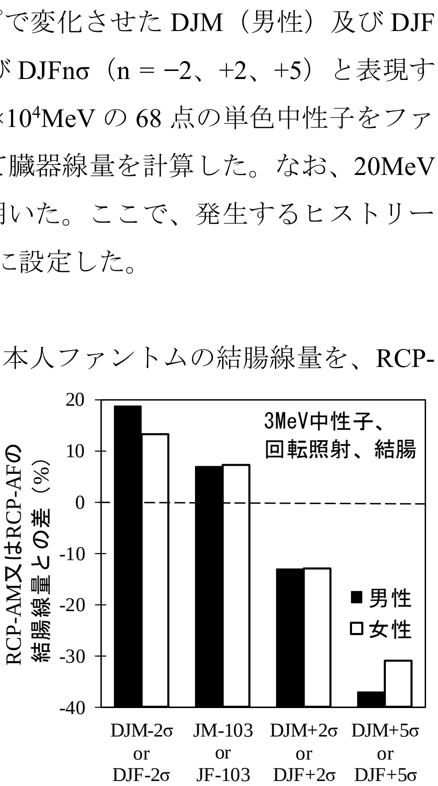

図 1 成人日本人ファントムの結腸線量

参考文献　[1] 保健物理 52, 247-258 (2017)., [2] ICRP Publication 116 (2010).

*Kaoru Sato[1], Daiki, Satoh[1], Fumiaki Takahashi[1] and Takuya Furuta[1]., [1]JAEA.

Evaluation of internal exposure effect in consideration of internal activation during boron neutron capture therapy

*Ryosuke Narita[1], Tatsuhiko Sato[2], Takushi Takata[3], Hiroki Tanaka[3] and Yoshinori Sakurai[3]

[1] Graduate school of Engineering, Kyoto University, [2] Japan Atomic Energy Agency, [3] Institute for Integrated Radiation and Nuclear Science, Kyoto University

Abstract The internal exposure due to the activation during BNCT was estimated by a Monte Carlo code "PHITS" with a computational phantom "MRKPs" and a risk calculation software "DCAL". The committed effective dose due to the internal exposure was almost 2.5 μSv and smaller than the external exposure of almost 180 mGy-eq.

Keywords: BNCT, Monte Carlo simulation, dose evaluation, activation, computational phantom

1. Introduction It is expected that boron neutron capture therapy (BNCT) using accelerator-based systems in hospitals will become widespread in near future. From the viewpoint of radiation protection and quality assurance for BNCT systems, it is important to estimate the exposure dose of the patient's normal tissue. Particularly, thermal and epithermal neutrons are incident to the patient, so that components constituting the body are possibly activated. Previous studies reported that the ^{24}Na and ^{38}Cl produced by activation were main components for the internal exposure[1],[2]. In order to evaluate the exposure dose more accurately, the effect of internal exposure for the neutron activation in the body was evaluated.

2. Material and Methods Simulations were performed for the typical BNCT studies for brain and head-and-neck tumors at a reactor-based BNCT system settled in Kyoto University Reactor (KUR). It was assumed that the concentrations of boron-10 in the normal tissues and blood were 25 ppm, the value of compound biological effectiveness (CBE) was 1.35 for normal tissue, and the irradiation time was 1 hour. First, the external exposure dose during BNCT was evaluated using a Monte Carlo code "PHITS[3]" with a computational phantom "MRKPs[4]". Second, the distribution of the neutron-induced radioactivity in the body was simulated by PHITS. Third, the dose equivalent and the effective dose for the internal exposure by neutron activation are estimated by a dose and risk calculation software "DCAL[5]".

3. Results For a case of the head-and-neck tumors, the equivalent dose due to the external exposure was estimated to almost 180 mGy-eq on the average for the whole body including the target volume. The committed effective dose due to the internal exposure was almost 2.5 μSv.

4. Conclusion The effect of the internal exposure due to the activation in BNCT on normal tissues was evaluated to be five orders smaller than the external exposure. Therefore, it is not essential to consider about the internal exposure for the daily treatment planning and QA/QC.

References

[1] Y. Sakurai *et al.*, A feasibility study of the post irradiation dose estimation with SPECT technique for BNCT, Appl. Radiat. Isot. 67(7-8, Supplement), S218-221, 2009.

[2] S. Nakamura *et al.*, Evaluation of radioactivity in the bodies of mice induced by neutron exposure from an epi thermal neutron source of an accelerator based boron neutron capture therapy system Proc. Jpn. Acad. Ser. B, 93(10), 821-831, 2017.

[3] T. Sato *et al.*, Features of Particle and Heavy Ion Transport code System (PHITS) ver sion 3.02, J. Nucl. Sci. Technol. 55(6), 684-690, 2018.

[4] C. Choi, *et al.*, Mesh type reference Korean phantoms (MRKPs) for adult male and female for use in radiation protection dosimetry, Phys. Med. Biol. 64(8), 085020, 2019.

[5] K. F. Eckerman, *et al.*, User's Guide to the DCAL System, ORNL/TM 2001/190, 2006, Oak Ridge National Laboratory..