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整合多模式影像資訊於螺旋式斷層治療
研究成果報告(精簡版)

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Integrate Mutil-modality Information in Image-guided Radiotherapy

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Abstract

Hybrid positron emission tomography/computed tomography (PET/CT) system enhances better differentiation of tissue uptake of ^{18}F-fluorodeoxyglucose (^{18}F-FDG) and provides much more diagnostic value in the non-small-cell lung cancer and nasopharyngeal carcinoma (NPC). In PET/CT, high quality CT images not only offer diagnostic value on anatomic delineation of hyper- and hypo-metabolic tissues but also shorten the acquisition time for attenuation correction (AC) compared with PET-alone imaging. The linear accelerators equipped with the X-ray cone-beam computed tomography (CBCT) imaging system for image-guided radiotherapy (IGRT) provides excellent verification on position setup error. The purposes of our study were to optimize the CT acquisition protocols of PET/CT and to integrate the PET/CT and CBCT for IGRT. The CT imaging parameters were modified in PET-CT for increasing the image quality in order to enhance the diagnostic value on tumour delineation. Reproducibility and registration accuracy via bone co-registration algorithm between the PET-CT and CBCT were evaluated by using a head phantom to simulate a head and neck treatment condition. Dose measurement in computed tomography dose index (CTDI) was also estimated. Optimization of the CT acquisition protocols of PET/CT was feasible in this study. Co-registration accuracy between CBCT and PET/CT on axial and helical modes was in the range of 1.06 to 2.08 and 0.99 to 2.05 mm, respectively. In our result, it revealed that the accuracy of the co-registration with CBCT on helical mode was more accurate than that on axial mode. Radiation doses in CTDI were 4.76 to 18.5 mGy and 4.83 to 18.79 mGy on axial and helical modes, respectively. Registration between PET/CT and CBCT is a state-of-the-art registration technology which could provide much information on diagnosis and accurate tumour contouring on radiotherapy while implementing radiotherapy procedures. This novelty technology of PET-CT and cone-beam CT integration for IGRT may have a potential becoming more clinical use in the future.

Keywords: PET-CT, cone-beam CT, IGRT, image registration

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1. Introduction

PET-CT system is considered as a significant advance in medical imaging technology. The hybrid PET/CT in one scanning procedure can produce both functional images with dedicated PET and intrinsically anatomical ones with CT, which serves as a transmission source in stead of Ge-68 source for PET-alone attenuation correction (AC) in PET images reconstruction [1,2]. This dual-modality imaging integrates perfectly functional and anatomical data to improve tumor localization and facilitate treatment planning for radiation oncology or surgery. It has been well acknowledged that the PET/CT system offers significant advantages over the conventional PET-alone, including greatly improved diagnostic value and increased accuracy in lesion localization. Dual-modality fused images also enhance better differentiation of tissue uptake of ^{18}F-FDG and provide much more diagnostic value in some sophisticated diseases especially in non-small-cell lung cancer and nasopharyngeal carcinoma (NPC). Image-guided radiotherapy (IGRT) [3] is a novel treatment system that could deliver highly conformal dose distribution with a high degree of geometrical and dosimetrical accuracy. Cone-beam CT, corresponding to x-ray volumetric imaging system (XVI) mounted on modern image-guided radiotherapy represents an advanced verification technology conducted in prior to each radiotherapy. Our study were to focus on the PET/CT to improve image quality by optimally modifying operating parameters of the CT and then to evaluate registration accuracy between PET/CT and XVI using an Alderson Rando Phantom for lifting probability of tumor control and decreasing tumor recurrence on NPCs.

2. Materials and methods

2.1. CT imaging parameters

An Alderson head Rando Phantom, which was attached six fiducial copper markers on it was used for localization on alternating operating parameters of the CT in a PET/CT system (Discovery LS, GE Medical Systems, USA) in order to improve CT image quality and registration accuracy between the PET/CT and the XVI imaging system. The PET/CT consists of a combination of a 64-slice CT and a high-resolution PET scanner. The default protocol of the helical CT is 140 kV (tube voltage), 80 mAs, 40 mm (collimation), 0.984 (pitch), 8 slices, and 5 mm (slice thickness), for routine head and neck studies. We designed protocols on axial mode with a fixed mAs (160 mAs) and different tube voltages (80, 100, 120, 140 kV) denoted as protocol 1-6 (P_1-P_6) and protocols with fixed tube voltage (140 kV) with varying mAs (80, 140, 200 mAs) denoted as protocol 5-7 (P_5-P_7). For helical mode, protocols with a fixed mAs (160 mAs) and different tube voltages (80, 100, 120 kV) denoted as protocol 8-10 (P_8-P_{10}) and protocols with a fixed voltage (140 kV) and different mAs (80, 120, 160, 200 mAs) denoted as protocol 11-14 (P_{11}-P_{14}) were also employed for optimization. The same protocols applied and repeated, very similar to those of P_{11}-P_{14} but with a different pitch (1.375) in stead of 0.984 denoted as protocol 15-18 (P_{15}-P_{18}).

For the planning CT (Siemens Somatom Sensation, Germany), protocols with a fixed mAs (150 mAs) and with different tube voltages (80, 100, 130 kV) denoted as control protocol 1-3 (C_1-C_3) and protocols with fixed voltage (130 kV) with varying mAs (80, 100, 150 mAs) denoted as control protocol 4-6 (C_4-C_6) as our experiment control sets.

2.2. PET image attenuation correction

A custom-made water phantom filled with 5.2 L water which was injected about 0.3 mCi 2-[Fluorine-18]-fluoro-2-deoxy-D-glucose (^{18}F-FDG) for PET emission attenuation correction (AC) was conducted with the parameters of the CT in PET/CT on both axial and helical modes between protocol P_1 and P_{18}. Corrected PET images were reconstructed with ordered subset expectation maximization (OSEM) algorithm (14 subsets, 6 iteration) adopting CT source for attenuation correction in stead of the traditional Ge-68 source rod in PET-standalone. The signal intensity profile of reconstructed PET images via CTAC on helical/axial mode was analyzed by Matlab software.

2.3. Estimation of the co-registration error

The XVI system consists of an X-ray kilovolt source and an amorphous silicon flat-panel imager mounted in a linear accelerator (Elekta, UK) was used in this study. To study an image positioning error between center of the CBCT, corresponding to the XVI isocenter P_{iso} and reference isocenter O_{iso} from CT, we took advantage of the build-in XVI software using cross correction algorithm [4] for co-registration. XVI scan was conducted for three times. Registration accuracy was determined by evaluating the selected overlapped image volume percentages between the XVI and CT. The potential sources of the error derived from the imaging co-registration involved: algorithm for fiducail marker localization, motion artifacts, loss and distortion of the images throughout compression and noise and voxel size of images. After finishing all the procedures between XVI and CT, we extracted all the data for calculating the centroids of the fiducial markers between XVI (X_i,Y_i,Z_i) and CT (X_0,Y_0,Z_0) and estimated the differences in the distance, defined as fiducial registration errors (FRE) between XVI and CTs using the calculated centroids and positioning errors (Eq.1).

$$\mathrm{FRE} = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2 + (Z_i - Z_0)^2} \quad \text{(Eq.1)}$$

Then we recorded the CT radiation doses on both axial and helical modes in PET/CT and planning CT using computed tomography dose index (CTDI) for the compromise between accuracy on radiotherapy and radiation dose on diagnosis.

3. Results

Fig.1 was the signal intensity profile of the uncorrected PET images and corrected ones via CTAC. In this study, corrected PET images via CTAC would acquire much better intensity profile and get better resolution than those in uncorrected ones. The signal intensity profile of the corrected PET images via CTAC had almost the same performance on both axial and helical modes. We had proved that corrected PET image throughout CTAC is essential and effectively.

In this study, four kinds of CT-XVI modality matching pairs, named XVI-CT_P (XVI and planning CT), XVI-CT_A (XVI and PET/CT on axial mode), XVI-CT_{H1} (XVI and PET/CT on helical mode with a pitch of 0.984), and XVI-CT_{H2} (XVI and PET/CT on helical mode with a pitch of 1.375) were evaluated. For the XVI-CT_P modality matching pair, the mean FRE of the co-registration with XVI between C_1 and C_6 using bone registration algorithm were in the range of 1.42 to 2.18 mm. For the XVI-CT_A modality matching pair, the mean FRE between protocol P_1 and P_7 were in the range of 1.06 to 2.08 mm and for the XVI-CT_H modality matching pair, the mean FRE between protocol P_8 and P_{18} were found in the range of 0.99 to 1.94 mm. The mean standard deviations of FRE in the XVI-CT_P, XVI-CT_A and XVI-CT_H were in the range of 0.39–1.57, 0.02–0.16, 0.04–0.17 mm, respectively. Comparison of FRE among the four modality matching pairs was demonstrated in Fig.2 which was expressed it seemed that the mean FRE of the co-registration in XVI-CT_{H1} was more accurate than that of co-registration in XVI-CT_P, XVI-CT_A and XVI-CT_{H2}. In Fig.2-(a), the tendency of FRE with the

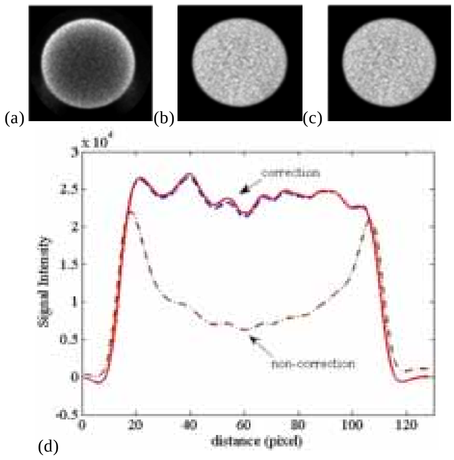

Fig.1 Comparison in signal intensity profile of uncorrected (a) and corrected PET images via CT attenuation correction with the parameters of 80 kVp and 160 mAs (b) and with 140 kVp and 200mAs on the axial mode (c). The same performance of corrected signal intensity profile was expressed on the helical mode.

increase in mAs in the XVI-CT_P, XVI-CT_A, XVI-CT_{H1} and XVI-CT_{H2} is much similar to each other. The tendency tends to go down with the increase in mAs and to fall down hastily at 160mAs. The same tendency existed in Fig.2-(b) which was shown the FRE tendency with the increase in tube voltage (kVp). FRE of the three modality matching pairs was about 2 mm but plumped abruptly when approaching 130-140 kVp. In addition, radiation dose in computed tomography dose index (CTDI) was as well as introduced to present the compromise between the radiation dose on diagnosis and accuracy on co-registration. Radiation dose in CTDI between the CT in PET/CT on axial and helical modes and planning CT were in the range of 4.76–18.5, 4.83–18.79 and 9.75–27.36 mGy, respectively. Radiation dose to CT of PET/CT are about 1.45 to 2.02 times lower than that in planning CT.

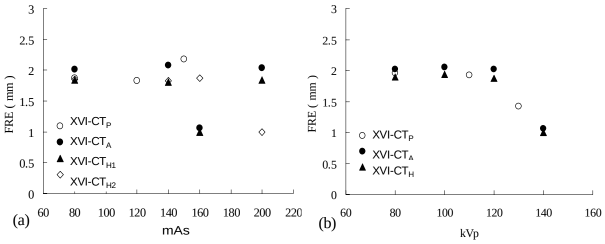

Fig. 2 the comparison of FRE among XVI-CT_P, XVI-CT_A, XVI-CT_{H1}, and XVI-CT_{H2} modality matching pairs with fixed tube voltage (kVp) and different mAs (a), and with fixed mAs and different kVp (b).

4. Discussion and conclusion

Advanced PET/CT can produce not only elaborately functional information from PET but also high quality anatomical information from CT. IGRT is a state-of-the-art radiation treatment system that could deliver highly conformal dose distribution with a very high degree of geometrical and dosimetrical accuracy. This study attempted to optimize the operating parameters of the CT in PET/CT using a head-and-neck anthropomorphous phantom to improve image quality both on the CT in contrast and on the PET in CTAC and evaluate the registration accuracy.

In this study, the registration accuracy in XVI-CT_{H1} was more accurate than that in XVI-CT_P, XVI-CT_A and XVI-CT_{H2}. So we suggest that conducting PET/CT on helical mode with a pitch of 0.984 be the better way to have co-registration with XVI while in verification. In addition, patients undergoing PET/CT will receive additional radiation dose from PET, but is negligible in comparison with radiotherapy and is deserved to have more diagnostic value than planning CT.

As to the abrupt drop phenomenon of FRE expression in Fig 2, it is not clear about the rapid variation. It maybe be derived from the random error of XVI imaging system, the image compression between XVI and PET/CT, the image size difference between XVI and PET/CT, and insufficient sample data acquired. This problem is deserved to discuss and analyze deeply to explain the phenomenon.

PET/CT itself possessed a staggeringly potential servicing as a practical radiation treatment plan tool, which is proved more accurate than that of the conventional CT. In addition, in combination of the high quality PET/CT with XVI, it not only increases the co-registration accuracy but the probability of tumor control and decreases the recurrence on NPC diseases. Our study result revealed that it may have a potential using a combination of this high quality PET/CT with IGRT in the clinical usage in the future when treating NPC diseases.

Acknowledgment

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出席國際學術會議報告

報告人姓名	蔡佳容	服務機構及職稱	陽明大學放醫所 博士生
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會議名稱	European Conference on Accelerators in Applied Research and Technology 2007		

一、會議介紹

本人蒙國科會之 NSC 95-2314-B-040 -023 計畫經費補助參加在義大利佛羅倫斯市所舉辦之2007年第九屆歐洲加速器應用與技術研討會 (9th European Conference on Accelerators in Applied Research and Technology)，「歐洲加速器應用與技術研討會」多年來，此研討會主要議程涵蓋加速器及相對應的技術、加速器發展應用於工業、加速器發展應用於醫學、同步加速器與放射線裝置、微小射束裝置與探測器、游離射束之物質校正、加速器分析技術應用於環境或其他用途、加速器質量光譜儀，目的是對於加速器應用在不同技術層面上的整合以及微小射束的發展提升有更深的認識與了解。本次大會更邀請四個研究單位(Lyncean Technologies; Institute for Particle Physics; Dipartimento di Elettronica e Informazione; National Technical University of Athens)分別就同步加速器、AMS系統、半導體偵測器、氘原子的發展作深入的探討介紹。由於此會議所函蓋的範圍甚廣，且與臨床實際運用能緊密的結合，這與本人多年來對於不同造影模式來推算臨床放射治療劑量研究上有著提昇研究廣度之幫助,特別是在使用MRI所得的影像資訊轉換為臨床放射劑量之基礎研究及整合。因此本次參與這次國際研討會必將獲得各國先進實驗室之研究成果及其心得。

二、與會心得

在此次會議第一天的議程裡分別就最近臨床上較流行的同步加速器做一系列的演講，由Ronald D. Ruth博士所主講的『The Compact Light Source: a miniature synchrotron』裡談到，目前發展出利用緊密的光射源(compact light source, CLS)來克服與改進同步加速器的問題。CLS是一種接近單一能量的X光射源，但可以產生比一般同步加速器小200倍的射源，且只要產生少量的射源便可達到以往同步加速器的效能。目前CLS系統以研究成功，未來將進一步樣本化與商業化，勢必可為同步加速器帶來更大的進展。

在第二天會議中，由Martin Suter所主講的『Small versus large AMS systems』裡談到，由於AMS系統裝置具有價格低廉、所佔空間小與容易操作的優點，因此近十年在放射線元素碳的年代偵測與生化放射線藥物研究上具有相當大的進展。在近期更發現將電壓能量提高的AMS系統裝置，可應用於輻射防護上。但由於能量越高所偵測的元素容易有同重元素的汙染，因此在特異性的辨識上仍是目前需要克服的問題。

在第三天會議中，由Carlo Fiorini所主講的『Semiconductor Drift Detectors for X and Gamma ray spectroscopy and imaging』談到，使用類半導體偵測器可以增加偵測光譜儀的解析度，此外將此類半導體偵檢器應用在X光與加瑪射束影像上，發現亦可增加其解析度。本人也認為此偵檢器的發展將可大幅應用在醫學影像與現今熱門之分子影像上，必可解決影像的解析度問題。

在第四天會議中，由Michael Kokkoris所主講的『A review on recent development in deuteron induced reactions enhancing NRA capabilities』談到，NRA具有高度射源篩選性的能力，且應用在氘分子上效果更顯著。目前利用NRA技術以探討出氘原子的特性，未來將針對其基礎原理做更進一步的研發。

三、攜回資料名稱之內容

ECAART 2007會議論文集以及相關會議之學術期刊。