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PHYSICS CONTRIBUTION

AUTOMATED FUNCTIONAL IMAGE-GUIDED RADIATION TREATMENT PLANNING FOR RECTAL CANCER

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Purpose: Computer tomography–based (CT-based) tumor-volume definition is time consuming and is subject to clinical interpretation. CT is not accessible for standardized algorithms for the purpose of treatment-volume planning. We have evaluated the accuracy of target-volume definition based on the positron emission tomography (PET) data from an integrated PET/CT system with 2-[^{18}F]fluoro-2-deoxy-D-glucose (FDG) for standardized target-volume delineation.

Materials and Methods: Eleven patients with rectal cancer who were undergoing preoperative radiation therapy (RT) were studied. A standardized region-growing algorithm was tested to replace the CT-derived gross tumor volume by the PET-derived gross tumor volume (PET-GTV) or the biologic target volume (BTV). A software tool was developed to automatically delineate the appropriate tumor volume as defined by the FDG signal, the PET-GTV, and the planning target volume (PTV). The PET-derived volumes were compared with the target volumes from CT.

Results: The BTV defined for appropriate GTV assessment was set at a single peak threshold of 40% of the signal of interest. Immediate treatment volume definition based on the choice of a single-tumor volume–derived PET-voxel resulted in a tumor volume that strongly correlated with the CT-derived GTV ($r^2 = 0.84$; $p < 0.01$) and the volume as assessed on subsequent anatomic-pathologic analysis ($r^2 = 0.77$; $p < 0.01$). In providing sufficient extension margins from the CT-derived GTV and the PET-derived GTV, to PTV, respectively, the correlation of the CT-derived and PET-derived PTV was sufficiently accurate for PTV definition for external-beam therapy ($r^2 = 0.96$; $p < 0.01$).

Conclusion: Automated segmentation of the PET signal from rectal cancer may allow immediate and sufficiently accurate definition of a preliminary working PTV for preoperative RT. If required, correction for anatomic precision and geometric resolution may be applied in a second step. Computed PET-based target-volume definition could be useful for the definition of standardized simultaneous internal-boost volumes for intensity-modulated radiation therapy (IMRT) based on biologic target volumes. © 2005 Elsevier Inc.

Functional imaging, Rectal cancer, Positron emission tomography, Preoperative radiotherapy, Radiotherapy planning.

INTRODUCTION

Target-volume delineation for the purpose of external-beam radiation therapy (RT) is an inherently observer-biased procedure to some degree and, according to the estimation of tumor extension, is differently appreciated by individual oncologists (1, 2). The International Commission on Radiation Units and Measurements (ICRU) 62 report proposed to standardize target-volume determination to obtain comparable volume definitions between radiation oncologists (3). An optimal and uniform target-volume definition is limited by the information obtained on the computer tomography (CT) used for dose calculation (4). CT has a relatively high spatial resolution but is limited in respect of specificity. However, 2-[^{18}F]fluoro-2-deoxy-D-glucose positron emission tomography (FDG-PET) can easily define macroscopic colorectal cancer tissue and improves staging accuracy before surgery or at restaging (5–8). The colocalization of PET signals with the CT is highly accurate for localizing pelvic disease (9). The specific activity of the FDG-PET signal improves the target-volume definition and may result in more homogenous target-volume definition between radiation oncologists (10, 11). Data from PET images may

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either be fused on CT data obtained on 2 different imaging sessions or may be coregistered on an integrated PET/CT system (11). The advantage of coregistration of PET and CT during 1 image acquisition session is that image-fusion deviations are reduced to less than 2 mm (12). Unfortunately, coregistered planning still requires time-consuming and oncologist-biased volume delineation. Radiation therapy (RT) may begin only after an additional waiting period which also contributes to patient distress.

More recently, the reliability of PET-determined lesions that represent macroscopic GTVs amenable to appropriate surgery or RT has been investigated, and these investigations have shown that treatment decisions can be changed by information obtained by the PET (13). For the purpose of external-beam RT, the PET signal may allow establishment of a standardized and highly reproducible volume-definition approach. Preliminary analysis *in vitro* and in a phantom measurements reveal a feasible and predictable rule to appropriately establish a target volume based on the FDG-PET signal (14, 15).

We have developed a tool that allows immediate and homogenous volume definition of rectal carcinoma before surgery, solely on the basis of the PET signal obtained for treatment-planning purposes in patients in the prone RT treatment position.

METHODS AND MATERIALS

Patients

A total of 11 consecutive patients were included in the present study. All patients presented with cT2 to cT3, cN0 to cN1, and M0 rectal cancer before surgery. Preoperative RT was performed in all patients. RT planning was performed on an integrated PET/CT scanner. Before i.v. administration of 10 mCi (370MBq) of FDG, patients fasted for 4 hours. The examination was started 45 to 60 minutes after the injection. The patient was positioned on the table in a head-first prone position with the assistance of a belly board to displace the small intestine out of the pelvis. CT data were acquired first.

Image acquisition

All imaging and data acquisition were performed on an integrated PET/CT system (Discovery LS; GE Medical Systems, Waukesha, WI). The device combines a GE Advance NXi PET scanner and a multislice helical CT (LightSpeed plus) in one system. The axes of both systems are mechanically aligned to coincide optimally. The offset between the CT and PET scanner-sensitive field of views along the table axis was 60 cm. Because of mechanical limitations, the table excursion was limited to 6 contiguous PET scans that covered a length of 86.7 cm. This excursion provided an axial field of view (FOV) from the head to the pelvic floor in all patients. CT scans were acquired first in normal expiration with the following scanning parameters: tube-rotation time 0.5 s/revolution, 140kV, 240 mA, 22.5 mm/rotation, slice pitch 6 (high-speed mode), and acquisition time 22.5 seconds for a scan length of 867 mm. No contrast was used. After the CT data acquisition had been completed, the tabletop with the patient was automatically advanced into the PET-sensitive field of view, and acquisition of PET emission data occurred with the patient in exactly the same position on the table. For each of the 6 scanning positions, 35 2-dimensional non–attenuation-corrected scans were acquired simultaneously over 4 minutes. For attenuation correction of PET data, the CT scans were reduced to the PET resolution by smoothing with an 8-mm full-width, half-maximum (FWHM) Gaussian filter. Then, the CT pixel values in Hounsfield units were transformed into linear attenuation coefficients in cm^{-1} at 511 keV by a bilinear function defined by the 3 coordinates ($-1{,}000$ HU, 0 cm^{-1}), (0 HU, 0.0933 cm^{-1}), and (1,326 HU, 0.172 cm^{-1}) (16). Transaxial, attenuation-corrected slices were reconstructed by iterative reconstruction. The PET and CT data sets were acquired by two independent computer systems, which were connected by an interface to transfer CT data to the PET scanner. Matched CT and PET images were reconstructed for a 500-mm field of view and with 4.25-mm slice thickness. An iterative reconstruction (OSEM with 2 iterations and 28 subsets) and CT-based attenuation correction were employed to reconstructing PET images with an in-plane resolution of about 7 mm.

Transfer of data to the planning systems

Data acquired on the PET/CT system were sent into PMOD 2.3, a commercially available quantification and modeling tool for medical imaging that includes an image gateway software package (PMOD Group, University Hospital, Zurich, Switzerland). Section selection covered the pelvis, and a set of 99 slices was selected from both the PET and the CT scans. The set of slices was limited to 99 because of the limited capacity of the RT-planning tool to accept image data. The data available in DICOM format were sent separately to a Pinnacle3 treatment-planning system (TPS) (Philips, Best, The Netherlands). Hardware coregistration was done by use of the same coordinate system. The CT data set was the primary image set used for dose calculation, and the PET data were used as an overlay. Matching accuracy was verified according to the match of the body contour and with fiduciary markers (marker GF-022 with an activity of 2.7 μCi, Isotope Product Laboratories, Valencia, CA). This procedure was performed to ensure that no major patient movement occurred between CT and PET data acquisition.

For computed automated delineation of PET signals, the PET data only were transferred in DICOM format without further slice selection. Processing was based on the sole detection of the signal of interest that represented the rectal cancer. After PET-based volume definition, the data set was transferred to the treatment-planning system in the DICOM format and used as an overlay for comparison with the volume outlines on the CT data set.

Tumor-volume delineation

The tumor volume was outlined manually on the TPS from the CT data set. FDG-PET data were transferred in a second step after automated volume delineation was preformed. Computed PET volumes were transferred to the TPS in the DICOM format and overlaid to the CT images following the same procedure as primary transfer of PET/CT data to the TPS. Anatomic-pathologic analysis was based on the pathologist description of the surgical specimen shown by tumor-volume extension in 3 dimensions.

Radiologic and anatomic tumor-volume correlation

All tumors underwent pathologic restaging after definitive surgery. Diameters were assessed in all 3 axes. The surgical specimen that described tumor-volume extension in 3 dimensions was extrapolated to the tumor volume by application of the formula $1/6\ p \cdot x \cdot y \cdot z$.