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ORIGINAL PAPER

Influence of different contributions of scatter and attenuation on the threshold values in contrast-based algorithms for volume segmentation

Roberta Matheoud [a], Patrizia Della Monica [a], Chiara Secco [a], Gianfranco Loi [a], Marco Krengli [b], Eugenio Inglese [c], Marco Brambilla [a,*]

[a] *Department of Medical Physics, Azienda Ospedaliero Universitaria ''Maggiore della Carità'', Novara, Italy*
[b] *Department of Radiotherapy, University of Piemonte Orientale, Novara, Italy*
[c] *Department of Nuclear Medicine, University of Piemonte Orientale, Novara, Italy*

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Abstract The aim of this work is to evaluate the role of different amount of attenuation and scatter on FDG-PET image volume segmentation using a contrast-oriented method based on the target-to-background (TB) ratio and target dimensions. A phantom study was designed employing 3 phantom sets, which provided a clinical range of attenuation and scatter conditions, equipped with 6 spheres of different volumes (0.5—26.5 ml). The phantoms were: (1) the Hoffman 3-dimensional brain phantom, (2) a modified International Electro technical Commission (IEC) phantom with an annular ring of water bags of 3 cm thickness fit over the IEC phantom, and (3) a modified IEC phantom with an annular ring of water bags of 9 cm. The phantoms cavities were filled with a solution of FDG at 5.4 kBq/ml activity concentration, and the spheres with activity concentration ratios of about 16, 8, and 4 times the background activity concentration. Images were acquired with a Biograph 16 HI-REZ PET/CT scanner. Thresholds (TS) were determined as a percentage of the maximum intensity in the cross section area of the spheres. To reduce statistical fluctuations a nominal maximum value is calculated as the mean from all voxel >95%. To find the TS value that yielded an area A best matching the true value, the cross section were auto-contoured in the attenuation corrected slices varying TS in step of 1%, until the area so determined differed by less than 10 mm^2 versus its known physical value. Multiple regression methods were used to derive an adaptive thresholding algorithm and to test its dependence on different conditions of attenuation and scatter.

The errors of scatter and attenuation correction increased with increasing amount of attenuation and scatter in the phantoms. Despite these increasing inaccuracies, PET

* Corresponding author. Tel.: +39 321 3733369; fax: +39 321 3733327.
E-mail address: marco.brambilla@maggioreosp.novara.it (M. Brambilla).

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threshold segmentation algorithms resulted not influenced by the different condition of attenuation and scatter. The test of the hypothesis of coincident regression lines for the three phantoms used provided no statistical basis for believing that the three lines are not coincident.

Calibration curves needed to implement contouring algorithms based on adaptive TS segmentation of PET volumes can be devised in different conditions of attenuation and scatter. This opens the possibility of defining a unified contrast-based method for target delineation in different anatomical districts.

Introduction

Although increasingly used in the clinical practice, the determination of tumour volume and shape from ^{18}F-flourodeoxyglucose (FDG) positron emission tomography (PET) in the course of radiotherapy planning remains a challenging task. Various approaches were reported in the literature to accurately contour FDG based gross target volume (GTV) [1]. Visual contouring by an experienced observer remains observer dependent [2]. Absolute thresholds such as a standardized uptake value (SUV) of a fixed value, e.g. 2.5, surrounding the lesion often fails when the physiological background activity lies above the fixed threshold [3]. Also the use of mean target SUV [4], or the use of a fixed percentage threshold, e.g. 40–50%, relative to maximum FDG accumulation of the lesions [5] are not suitable for GTV contouring [6]. Methods for segmentation based on contrast-oriented contouring algorithms [3,7–9] have been developed independently by many groups and validated in patient data both in head and neck [10] and in lung cancer [11] with satisfactory results. Methods for segmentation of non uniform tracer concentration not based on thresholding have been recently proposed [12,13]. While referring to these promising methods it should be pointed out that until they are further developed and validated, contrast-oriented segmentation methods are and will be used in most clinics and therefore need to be accurately characterized.

The use of contrast-based segmentation methods is driven by the low quality of PET images in terms of resolution and statistical noise. These methods rely on a scanner-specific calibration curve, which depends on object properties such as target-to-background (TB) ratio [5,7,14] and target size [14–16], and imaging parameters such as reconstruction algorithm and smoothing filter [7,15]. We recently demonstrated that, among acquisition parameters, emission scan duration and background activity concentration, both related to total number of counts and to the level of image noise, did not result as significant predictors in threshold determination in the ranges explored [14]. The influence of different conditions of attenuation and scatter on contrast-based algorithms, used to define the boundaries of FDG uptake has not been fully explored in literature. This is of clinical relevance since, if different conditions of attenuation and scatter would play a role, site-specific calibration curves should be devised at least for a coarse subdivision of whole-body imaging such as, for instance, head and neck, thorax and abdomen. On the other hand, the finding that PET image segmentation is independent on scatter and attenuation would suggest that contrast-based contouring algorithms need not to be regarded as site specific and may be applied irrespective of the phantom used in their derivation.

In hybrid PET/CT scanner, attenuation correction is performed using CT data, scaled to 511 keV [17]. Several approaches to the problem of scatter correction have been proposed and are currently used including analytical corrections [18], Monte Carlo simulations [19], background subtraction or tail fitting methods [20]. A standardized way to quantify the accuracy of correction for attenuation and scatter has been provided in the NEMA NU2-2001 (NEMA01) standard [21] as the relative error in percentage units of the intensity within a region of the lung insert of the International Electro Technical Commission (IEC) body phantom set compared to the background intensity: values of 32% and 13% have been reported by Erdi et al. [22] using a CPS Accel PET/CT scanner and attenuation-weighted ordered-subset expectation maximization (OSEM) iterative reconstruction with 2 iterations and 8 subsets and 4 iterations and 16 subsets, respectively. Similar values (34% and 17%) were obtained by our group using a Biograph HI-REZ PET/CT scanner [23]. Bettinardi et al. [24] reported a value of 16% using a Discovery ST PET/CT scanner in 3D acquisition mode and OSEM (3 iterations, 32 subsets) reconstruction. In a recent inter-laboratory comparison study of image quality of PET scanner, Bergmann et al. [25] reported relative errors for the attenuation and scatter correction, for 8 dedicated PET systems for which attenuation correction was routinely used, in a range of 26–49%. Moreover, they demonstrated a significant negative correlation of this relative error with a contrast quality index, defined as the sum of all contrast values measured on the 6 IEC phantom spheres.

Our aim is to show that, also with simplified phantom geometries as those selected in this study, the accuracy of correction decreases with increasing amount of attenuation and scatter in the phantom being imaged. To this purpose an experiment was designed in which the accuracy of correction for attenuation and scatter was assessed in three phantom sets representing different conditions of attenuation and scatter, assessed by conventional measures of noise equivalent count rate (NECR) and scatter fraction characteristics. We previously provided evidence that the modification of the IEC phantom used in the experiment generates counting rates that are relevant to predict what would happen in human imaging [26]. Based on these results, an adaptive thresholding algorithm based on contrast and lesion size was developed. The impact of