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The age of reason for FDG PET image derived indices

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The clinical use of Positron Emission Tomography (PET) imaging using the 2-deoxy-2-(18F)fluoro-D-glucose (18F-FDG) is currently predominantly focused on diagnostic purposes within the field of oncology. Within this context, image analysis is largely based on visual interpretation and the use of simple image derived indices, such as the maximum standardised uptake value (SUV_{max}), which corresponds to the voxel with the maximum activity concentration within the tumour scaled by the administered activity, patient weight and blood glucose concentration. On the other hand, during the last few years there has been increasing interest in the use of 18F-FDG PET imaging for the prediction and monitoring of therapy response. Within this context the SUV_{max} has been also predominantly used, where differences between a pre-treatment and post-treatment scan have been shown to closely correlate with clinical response to treatment for a number of different cancer models [1,2].

The clear advantage of such a simplistic image derived index is the easiness of use which has significantly contributed to its widespread application in clinical practice. SUV_{max} is also in principle less dependent to partial volume effects (PVE), resulting from the limited spatial resolution of PET imaging [3]. On the other hand, there are a number of issues associated with its use, such as lack of robustness in terms of image noise, as well as in terms of the reconstruction algorithm and the associated corrections used during the reconstruction process. Clearly the impact of these issues can be minimised by standardisation of the injection, acquisition, and finally image reconstruction and analysis protocols. In addition, the use of peak SUV (SUV_{peak}), measured by averaging the voxel values inside a small region of interest centered on the tumor maximum activity concentration voxel, can reduce the SUV_{max} sensitivity to noise, although results may be sensitive to the actual definition of the ROI used to compute SUV_{peak} [4]. However and most importantly, SUV_{max} represents only very limited information considering the radiotracer accumulation and no information on the associated tumour uptake distribution as well as on the overall tumour functional volume. This is true even within the context of static acquisitions associated with routine whole body 18F-FDG PET imaging, where one does not consider dynamic acquisitions which offer the possibility, through kinetic modelling, to derive quantitative glucose metabolic rates on a voxel by voxel basis.

Remaining within the context of static PET imaging, overall tumour activity accumulation can be alternatively characterised using the mean standardised uptake value (SUV_{mean}). SUV_{mean} corresponds to the mean activity concentration within a

delineated three dimensional functional tumour volume. The most significant issues associated with the accuracy of SUV_{mean} determination include the precision and robustness in the delineation of the tumour functional volume used [5,6], as well as an important influence of PVE which is closely related to the overall tumour size. The impact of PVE becomes more significant in the case of response to therapy studies where the metabolically active tumour volume (MATV) may change during treatment, consequently introducing a variable PVE influence on the calculated difference in SUV_{mean} between the baseline and the post-treatment image. All these dependence issues combined with the lack of robust tools for tumour volume segmentation and PVE correction in PET oncology imaging has previously limited the widespread use of SUV_{mean} .

A combination of the metabolically active tumour volume (MATV) and the SUV_{mean} , defined as the total lesion glycolysis (TLG) or total glycolytic volume originally proposed by Larson et al [7], would allow in principle a more comprehensive functional tumour characterisation. The advantage of such an index is that it includes the average level of uptake within the tumour in addition to the spatial extent of the tumour uptake distribution, which facilitates the discrimination between lesions with similar size, but different uptake levels and vice-versa. The potential clinical impact of using such a parameter, reflecting overall tumour metabolic information rather than a single or few voxel measures based on SUV_{max} or SUV_{peak} respectively, has been recently demonstrated. TLG levels derived from a baseline PET image were able to predict, in contrast to SUV_{max} , response to therapy in different cancer models, including mesothelioma [8], lymphoma [9] and oesophageal carcinoma [10].

However, despite their potential value, image derived indices such as 3D MATV and TLG have found only limited use up to date, including within the context of recent recommendations for response to therapy assessment using ^{18}F -FDG PET imaging [11]. This can be mostly explained by the limited accuracy, robustness and reproducibility of the clinically available tumour delineation tools. The shortcomings of standard threshold based approaches for MATV, which are currently the only widely available in clinical practice, have been previously highlighted in the literature [6,12]. They include a strong dependence on overall tumour volume and contrast. On the other hand, manual MATV delineation is a time consuming process prone to high inter- and intra-operator variability [13]. This renders manual tumor delineation a non-viable tool for allowing the introduction of MATV as an image derived index in routine

clinical practice. Different automatic segmentation approaches have been recently proposed, motivated by the interest of using 18F-FDG PET for the MATV delineation within the field of radiotherapy treatment planning [14]. Some of these approaches have shown high robustness and reproducibility to variable quality PET images (depending on factors such as scanner sensitivity and image reconstruction parameters) and tumour activity distribution characteristics, allowing similar to SUV_{max} physiological reproducibility limits [15]. In addition, the use of these approaches has shown promising results for employing MATV measures in the prediction and prognosis of response to therapy based on 18F-FDG PET imaging [6,10]. However, being able to accurately determine a 3D functional tumour volume does not obviate the need for partial volume effects correction in order to ensure the calculation of an accurate tumour SUV_{mean} . This extra step clearly further complicates the process of accurately determining TLG values.

For all these reasons a novel parameter entitled SAM or “standardized added metabolic” activity parameter, recently proposed by Mertens J and colleagues [16] in the European Journal of Nuclear Medicine and Molecular Imaging, may be of particular interest. The attractiveness of this parameter is its potential independence to an accurate MATV determination as well as partial volume effects. Its derivation is based on considering the product of the concentration of activity and corresponding volume within two manually defined concentric volumes of interest (VOIs). These VOIs are placed around the tumour in sufficient distance from the MATV border to avoid partial volume effects. The concentration of activity in the difference VOI is used to determine the background activity which is subtracted by the SUV_{mean} derived using the VOI closer to the tumour. Although this parameter contains information related to both MATV and SUV_{mean} it does not provide precise 3D tumour volume measurements and as such does not require an accurate MATV segmentation algorithm or manual tumour delineation. At the same time the mean tumour activity concentration calculated within the context of SAM is in principle not influenced by partial volume effects. In this same study it was also shown that SAM was less influenced by noise compared to the SUV_{max} . Finally, a potential dependence on the scanner calibration and activity injection parameters can be excluded using a “normalized SAM” version by dividing the calculated tumour SAM value with the mean background SAM, assuming that the background and the tumour will be equally influenced by the different acquisition factors.

A preliminary clinical evaluation of this new PET image derived parameter was performed as part of the same study [16] considering 19 colorectal carcinoma patients undergoing baseline and treatment follow-up PET scans (after 3-6 chemotherapy cycles). In this patient population, consisting of only responders and non-responders, no statistically significant differences were found between SUV_{max} or SAM for assessing response to therapy based on PET imaging. This was the case considering either the baseline PET image values or differences between the baseline and the follow-up scans. More studies are now necessary considering different cancer models and larger and more variable patient populations in order to demonstrate the value of SAM not only compared to SUV_{max} but also in comparison to other ^{18}F -FDG PET image derived parameters such as 3D MATV and TLG values in terms of both prediction and assessment of response to therapy.

One can imagine going even further in exploiting tumor activity distribution features extracted from static PET images. These include assessing different levels of tumour uptake distribution heterogeneity which can eventually correlate with the underlying physiological processes governing tumor function. Since some of these physiological processes are potential mediators or targets of different therapeutic regimes, such image derived indices can be also proposed within the context of therapy response prediction and prognosis. Some recent studies have shown the interest of such indices for predicting response to therapy in head and neck [17], cervical [17] and esophageal cancer [18].

Finally it may be appropriate to combine multiple PET image derived indices and even multimodality and/or multi-tracer image derived parameters for a more complete tumor characterization. Complex correlations will have to be considered given the complexity of underlying tumour biology. Molecular profiling of biological specimens allows today to reveal the expression level of multiple genes and proteins. Obtaining biological specimens requires invasive procedures and may depend on the location of the biopsy within a tumour. Would it be ever possible to imagine as an alternative the use of multimodality imaging, combining different image derived indices that will be identified as gene expression specific “signatures” and as such allow a non-invasive molecular profiling of individual patient cancers? This is still a dream but based on a few existing studies we may consider this idea as a future target for becoming reality [19]. Only future will tell.....

In conclusion, we have available today a number of algorithms and approaches that allow the automatic or semi-automatic extraction of accurate quantitative parameters from the tumor activity distribution in static ^{18}F -FDG PET images. We have in this sense reached the age of reason in PET image derived parameters. There is now an urgent need for these tools to become widely available in order to allow the clinical research community to demonstrate their potential interest for therapy assessment, therapy response prediction and patient survival in different cancer models. A first step within this process involves standardization, robustness and reproducibility studies for all these “novel” PET image derived indices in comparison to current “state of the art” in clinical use such as SUV_{max} .

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