Original

Nuclear Medicine Review 2022, 25, 2: 112–118
DOI: 10.5603/NMR.a2022.0035

ISSN 1506–9680, e-ISSN 1644–4345

VIA MEDICA

Value of diffusion MRI versus [18F]FDG PET/CT in detection of cervical nodal metastases in differentiated thyroid cancer patients

Ahmed M. Shalash[1], Mai Amr Elahmadawy[2], Samia Y. Heikal[1], Ayman A. Amin[3], Ayda A. Youssef[1]
[1]Department of Diagnostic Radiology, National Cancer Institute, Cairo University, Egypt
[2]Nuclear Medicine Unit, National Cancer Institute, Cairo University, Egypt
[3]Department of surgery, National Cancer Institute, Cairo University, Egypt

[Received: 3 I 2022; Accepted: 30 VI 2022]

Abstract

Background: In differentiated thyroid cancer (DTC) patients, cervical nodal metastasis is a negative prognostic factor. Preoperative imaging plays an important role in treatment planning for nodal metastasis and recurrence.

The aim of the study is to compare the diagnostic performance of the diffusion-weighted magnetic resonance imaging (DW-MRI) and the F-18 flurodeoxyglucose positron emission computed tomography ([18F]FDG PET/CT) in detection of cervical nodal deposits in DTC patients.

Materal and methods: The study was conducted on 30 patients, each performed both modalities just before the surgery. The gold standard was the pathological specimens with post-operative clinico-radiological follow-up, to assess the diagnostic performance of each modality.

Results: Based on pathological and post-operative clinico-radiological follow up data. Sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV) and accuracy were 84%, 80%, 50%, 95% and 83% for PET/CT compared to 84%, 60%, 42.8%, 91.3% and 80% for DW-MRI.

On comparing the diagnostic performance of combined DW-MRI and PET/CT to each modality alone, the sensitivity and NPV were improved to 96% and 80% respectively.

Conclusions: [18F]FDG PET/CT study is a valuable diagnostic modality for the assessment of cervical nodal deposits in DTC patients, surpassing DW-MRI. Combined PET/CT and DW-MRI techniques seemed to have synergistic performance, mainly in terms of sensitivity and NPV, for detection of nodal metastases.

KEY words: DW-MRI; PET/CT; DTC; cervical nodal metastasis

Nucl Med Rev 2022; 25, 2: 112–118

Introduction

Differentiated cancer thyroid (DTC) has shown an increasing incidence over the last few decades [1]. It is distinguished by its multimodal therapeutic approach which is individualized and risk-adapted [2]. Surgery is considered a cornerstone of initial management followed by adjuvant radioactive iodine in indicated cases [3].

High-risk DTC is also known for its high rate of local recurrence and lymph node or soft tissue metastases; roughly calculated range is between 20% and 30%, other studies stated that the recurrence rate may reach up to 40% [4]. Distant metastases develop in up to 15% of cases, primarily as pulmonary metastases followed by bone metastases [5]. Prognosis mainly is depending on the site of recurrence. Whenever feasible, surgical re-intervention

Correspondence to: Mai Amr Elahmadawy, Nuclear Medicine Unit, National Cancer Institute (NCI), Cairo University, Foam Elkhalig, 11026 Cairo, Egypt, e-mail: Mai.elahmadawy@nci.cu.edu.eg

is the treatment of choice in cases of cervical nodal metastases and loco-regional recurrence before considering radioactive iodine or radiation therapy [5].

Differentiated cancer thyroid (DTC) risk stratification is a dynamic process that depends on using multiple staging systems and targets precise therapy tailoring with prediction of risk for recurrence and disease-relatedmortality [6]. Therefore, cervical nodal metastasis identification by preoperative imaging efficiently contributes to treatment planning [7].

[^{18}F]FDG PET/CT was shown to be an efficient imaging study in disease localization in patients with elevated thyroglobulin (Tg) levels, negative US, and I-WBS [5]. It was quickly surpassed by [^{18}F]FDG PET/CT, which combined the advantages of metabolic and morphologic imaging. [^{18}F]FDG PET/CT is accepted as the study of choice for post thyroidectomy patients with increased Tg blood levels and negative I-WBS [8]. However, recurrent, residual, or metastatic tissue does not always accumulate [^{18}F]FDG and consequently remains undetectable by [^{18}F]FDG PET/CT. As a consequence, supplementary imaging modalities performance may be needed to be also assessed in this aspect [5].

Magnetic resonance imaging (MRI) is the primary imaging modality for soft tissue neoplasms owing to its superior soft tissue contrast, additional functional imaging abilities, and reduced dental metal artifacts as compared to [^{18}F]FDG PET/CT [9].

Diffusion-weighted imaging (DWI) and apparent diffusion coefficient (ADC) measurements are being considered potentially useful in the assessment and characterization of head and neck different lesions. DWI can differentiate the viable and necrotic portions of head and neck tumors. The ADC can discriminate benign lesions from malignant tumors and tumor necrosis from abscesses [10].

Although DW-MR is not a routine investigation when evaluating thyroid cancer, it may become one of the choices owing to the efficiency of MRI for tumor diagnosis [11]. So, in the current study, we compared DW-MRI *vs.* [^{18}F]FDG PET/CT for the detection of cervical nodal metastases either in initially assessed patients with pathologically proven DTC or those with suspected loco-regional recurrence.

Material and methods

This prospective study included 30 adult patients represented between the period of December 2017 and January 2020. All patients were referred to perform MRI and DW-MRI as well as [^{18}F]FDG PET/CT respectively, either for initial nodal staging or detection of clinico-laboratory suspected nodal recurrence in pathologically proven differentiated thyroid cancer (DTC).

Clinical information was extracted from the medical records. The study has been approved by the ‘‘Ethical Committee”, with Institutional Review Board (IRB) number (201617077.3).

Inclusion criteria

- adults (>18 years),
- pathologically proven DTC Patients with initially high-risk clinico-pathological criteria,
- patients with clinical suspicion for local nodal deposits based on radiological (e.g.: sonography) and/or elevated tumour markers (rising Tg with negative I-131 WBS),
- patients eligible for surgical management.

Exclusion criteria

- pediatrics patients (<18 years old),
- double primary patients,
- contraindicated surgical management (i.e.: palliative inoperable or not fit for anesthesia or surgery),
- patients previously treated with local radiation therapy,
- general contraindications for performing PET/CT or MRI.

Patients' preparation and imaging techniques

[^{18}F]FDG PET/CT

- patients were instructed to fast for at least 4–6 h before the study,
- the fasting blood glucose level was determined with preferred fasting blood glucose below 150 mg/dL,
- [^{18}F]FDG PET/CT study was done using a dedicated Discovery PET/CT scanner (GE Medical System, USA),
- scanning started 45–60 min after tracer injection of about 0.15 mCi/kg,
- no CT contrast agents were administered,
- the images were interpreted by 1 experienced nuclear medicine physician blinded to the results of histopathology,
- images were interpreted through visual qualitative (visual) assessment where any regional lymph node regardless of the CT size exhibiting focal FDG uptake, superior to physiological background activity was interpreted as a positive node,
- quantitative assessment was performed by recording the maximum standardized uptake values (SUV_{max}) for the node with the highest activity.

DW-MRI

- the patients had their MRI done on a high field system (1.5 Tesla) closed magnet unit (Phillips Achieva XR),
- the MRI technique included multiplanar MR imaging sequences without contrast including T1, T2, and STIR WIs as well as DW sequence with multiple b-values (b-0, 400 and 800),
- the DW-MRI was visually interpreted (qualitative assessment) by three experienced radiologists. "Positive" was diagnosed when a definite abnormal localized area of diffusion restriction was noted as a high signal lesion confirmed by histopathological examination.
- regarding the quantitative analysis of DWIs, we measured the ADC at the most restricted area within the lesions.

Both DW-MRI and [^{18}F]FDG PET/CT findings were verified on the basis of

- histopathological data (obtained from surgical specimens),
- operative data and post-operative CT, MRI, and/or [^{18}F]FDG PET/CT imaging findings.

Statistical analysis

Continuous data are summarized in terms of mean and standard deviation. Categorical data is represented in terms of frequency and percentage (%). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each modality. We used the McNemar test to compare the discriminatory performance of two different modalities. ROC curve was used to assign the most appropriate cutoff value. We used R version 4.0.0 in this analysis.

Results

The 30 enrolled patients were 10 males and 20 females with age ranged 22–77 years, with pathologically proven DTC, referred either for initial nodal staging (in 4 patients) or detection of clinico-laboratory suspected nodal recurrence (in 26 patients) with rising Tg serum level and negative I-131 WBS. Serum TG levels for our group — under TSH suppression — was (median 25.20 ng/mL, range, 2–85 ng/mL). All patients performed both DWI-MRI and [^{18}F]FDG PET/CT techniques to assess the ability of each modality to detect cervical nodal metastasis. The main clinico-pathological characteristics of the study group are illustrated in (Supplementary Tab. 1).

Based on histopathology and post-operative clinico-radiological data and follow-up, out of the 30 investigated patients, 25 patients were positive for cervical nodal metastases (23 metastatic papillary carcinoma and 2 metastatic follicular carcinoma) while the remaining 5 patients revealed benign hyperplastic, inflammatory changes or primary disease without nodal metastasis. The time to recurrence ranged from 2 to 90 months.

Most of the cases were assessed radiologically by ultrasound neck examination (27 cases) and the remaining 3 cases were assessed by CT. Though the Ultrasound showed relatively reasonable sensitivity, PPV, and accuracy of 77%, 85% and 70.3% respectively, however, its specificity and NPV were as low as 40% and 28% respectively.

Comparison of diagnostic performance between different modalities

Based on the obtained pathological data, an attempt to compare the diagnostic performance of [^{18}F]FDG PET/CT and DW-MRI was performed.

Sensitivity, specificity, NPVand PPV were 84%, 80%, 50%, 95% for [^{18}F]FDG PET/CT compared to 84%, 60%, 42.8% and 91.3% for DW-MRI. Relatively higher specificity indices were noted with [^{18}F]FDG PET/CT compared to DW-MRI; however, it was not statistically significant (p = 0.31), but reflected in the diagnostic accuracy, which was 83% for [^{18}F]FDG PET/CT compared to 80% with diffusion MRI (Tab. 1).

Agreement of results was tested between [^{18}F]FDG PET/CT and DW-MRI. True positive agreement was found in 18 patients out of 25 (Supplementary Fig. 1). False-negative agreement was noted in 1 patient, while disagreement was found in 6 patients with equal share in false-negative results by both modalities (Fig. 1).

Among the 5 patients who were pathologically proven to be free from nodal metastases, when comparing [^{18}F]FDG PET/CT and DW-MRI were in agreement in 3 true negative patients. One false-positive agreement noted and one case of disagreement between both modalities was found which was truly negative with [^{18}F]FDG PET/CT and falsely positive with DW-MRI (Fig. 2).

Table 1. Diagnostic performance of [^{18}F]FDG PET/CT versus DW-MRI in nodal assessment (No. of patients = 30)

Modality	[^{18}F]FDG PET/CT	DW-MRI	p-value
True positive	21 (70%)	21 (70%)	
False positive	1 (3.3%)	2 (6.7%)	
True negative	4 (13.3%)	3 (10%)	
False negative	4 (13.3%)	4 (13.3%)	
Sensitivity	84%	84%	1
Specificity	80%	60%	0.31
Accuracy	83%	80%	
PPV	95%	91.3%	0.32
NPV	50%	42.8%	0.67

[^{18}F]FDG PET/CT — F-18 flurodeoxyglucose positron emission computed tomography; DW-MRI — diffusion-weighted magnetic resonance imaging; NPV — negative predictive value; PPV — positive predictive value

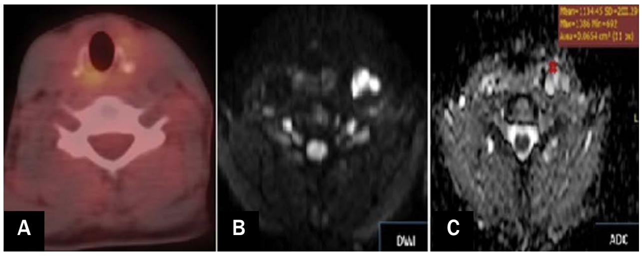

Figure 1. 31-year-old woman presented with PTC, underwent total thyroidectomy. Follow up assessment (3 months post-thyroidectomy): revealed rising TG level reached 7.1 ng/mL. PET/CT showed no FDG avid lesions (**A**). Conventional MRI showed left cervical level IV lymph node with suspicious features with bright signal on diffusion mostly T2 shine through effect (**B**), high ADC value = 1.1 × 10^{-3} mm^2/s (**C**). Pathological assessment revealed: metastatic papillary carcinoma

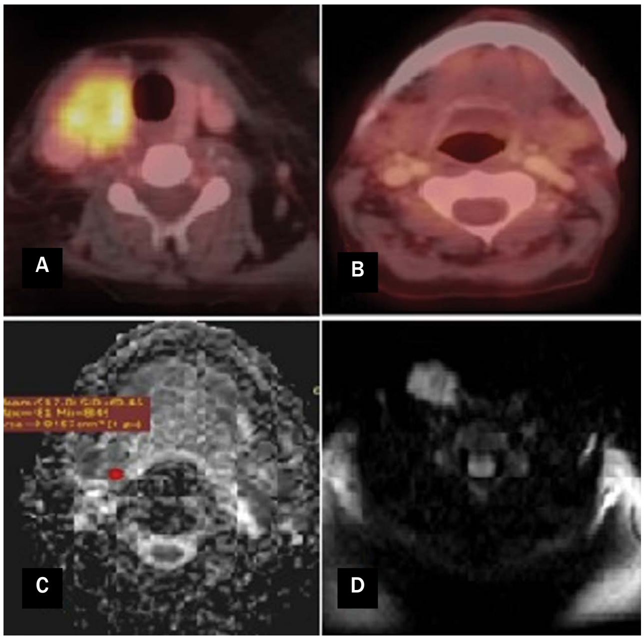

Figure 2. 50-year-old woman initially presented with de-novo neck swelling. PET/CT revealed: right thyroid lobe FDG avid focal lesion (**A**). Non-FDG avid right upper deep cervical nodes (level II; **B**). MRI showed right thyroid lobe focal nodular lesion, eliciting low T1 and intermediate T2 signal intensities. Clustering Right upper deep cervical lymph nodes (level II) with effaced fatty hilum, some of them are rounded & globular shape with irregular boarder, eliciting low T1 and intermediate T2 signal intensities. DWI and ADC map revealed Restricted diffusion for the thyroid nodular lesion as well as restricted diffusion and reduced ADC value (0.9 × 10^{-3} mm^2/s) for the nodal lesion (**C**). The patient underwent surgical interference with total thyroidectomy and right radical neck dissection. Pathology revealed papillary thyroid carcinoma and inflammatory changes of the upper deep cervical lymph nodes

The total fore mentioned disagreement of modalities in 6 patients out of 25 patients with positive nodal metastasis can be explained by the different diagnostic positive criteria on which different modalities rely. Such observation called for a further need to analyze the synergistic diagnostic potential that could be obtained through combining both modalities.

Diagnostic performance of Single versus combined modalities

On comparing the diagnostic performance of combined DWI-MRI and PET/CT compared to [18F]FDG PET/CT alone, it was noted that only one true positive case was missed, which was consequently reflected in sensitivity indices that were notably higher with combined modalities, where the sensitivity of 96% and NPV of 80% was obtained compared to 84% and 50% with [18F]FDG PET/CT alone. A trend for statistical significance was noted with p-value 0.08 and 0.07 for sensitivity and NPV respectively (Tab. 2).

Higher sensitivity indices were also noted when comparing DWI-MRI to combined DWI-MRI and [18F]FDG PET/CT modalities, with the sensitivity of 84% and 96% and NPV 42.8% and 80% for DWI--MRI versus combined modalities respectively, which was statistically significant (p-value = 0.04) for NPV and shows a trend for statistical significance (p-value = 0.08) was noted for sensitivity (Tab. 3).

Table 2. Diagnostic performance of [18F]FDG PET/CT versus combined DW-MRI and PET/CT in detection of nodal metastases (No. of patients = 30)

Modality	[18F]FDG PET/CT	Combined DWI-MRI and PET/CT	p-value
True positive	21 (70%)	24 (80%)	
False positive	1 (3.3%)	1 (3.3%)	
True negative	4 (13.3%)	4 (16.6%)	
False negative	4 (13.3%)	1 (3.3%)	
Sensitivity	84%	96%	0.08
Specificity	80%	80%	1
Accuracy	83%	93%	
PPV	95%	96%	0.08
NPV	50%	80%	0.07

[18F]FDG PET/CT — F-18 flurodeoxyglucose positron emission computed tomography; DW-MRI — diffusion-weighted magnetic resonance imaging; NPV — negative predictive value; PPV — positive predictive value

Table 3. Diagnostic performance of DW-MRI versus combined DW-MRI and PET/CT in detection of nodal metastases (No. of patients = 30)

Modality	DWI-MRI	Combined DWI-MRI and PET/CT	p-value
True positive	21 (70%)	24 (80%)	
False positive	2 (6.7%)	1 (3.3%)	
True negative	3 (10%)	4 (16.6%)	
False negative	4 (13.3%)	1 (3.3%)	
Sensitivity	84%	96%	0.08
Specificity	60%	80%	0.31
Accuracy	80%	93%	
PPV	91.3%	96%	0.23
NPV	42.8%	80%	0.04

[18F]FDG PET/CT — F-18 flurodeoxyglucose positron emission computed tomography; DW-MRI — diffusion-weighted magnetic resonance imaging; NPV — negative predictive value; PPV — positive predictive value

Quantitative-based image analysis

DW-MRI ADC cut-off value

A cut-off value is defined as the criterion value range that predicts a positive condition. It was calculated by evaluating 71 nodes at different neck levels. The minimum and maximum ADC values were found to be 0.53 and 2 respectively, eliciting 1.04 as a mean ADC value, with a 0.26 standard deviation.

Receiver operating characteristic (ROC) analysis showed that the area under the curve was 0.69 and the optimum threshold for the ADC was $1.01 \times 10^{-3} mm^2/s$ with sensitivity, specificity, accuracy, and PPV of 61%, 80%, 68%, and 85% respectively being plotted on ROC curve with p = 0.001, denoting the significance of the applied data (Fig. 3).

[18F]FDG PET/CT cut-off value

A cut-off value indicates the identification of the value range that predicts a positive condition. It was calculated by evaluating 54 nodes at different neck levels. The minimal and maximal SUV were found to be 1.6 and 46.3 respectively, with a mean value of 8.6 and a standard deviation of 9.9.

ROC analysis showed that the area under the curve was 0.88 and the optimum threshold for the SUV was 3.1 with sensitivity, specificity, accuracy, and PPV of 81%, 83%, 81% and 98% respectively, being plotted on ROC curve (Fig. 4), with p = 0.002, denoting the significance of the applied data.

Discussion

So far only a few published studies conducted Head-to-Head Comparison of [18F]FDG PET/CT and DW-MRI in the detection of initial or recurrent regional nodal metastases from DTC [11].

In the current study, 21 patients out of 30 patients were detected by DW-MRI as true positive patients eliciting 70% as detectability, while Nagamachi S et al. [11], whose study was conducted on 59 patients with DTC, from which, 34 patients with positive nodal deposits were detected by DW-MRI and thus eliciting (57.6%) as detectability.

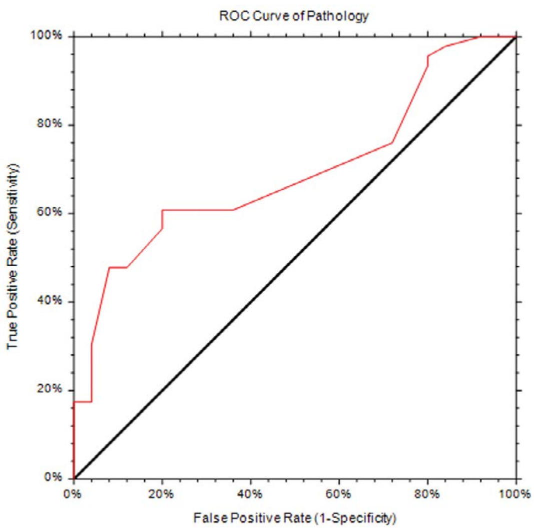

Figure 3. ROC curve for ADC cutoff; AUC = 69% and p-value = 0.001

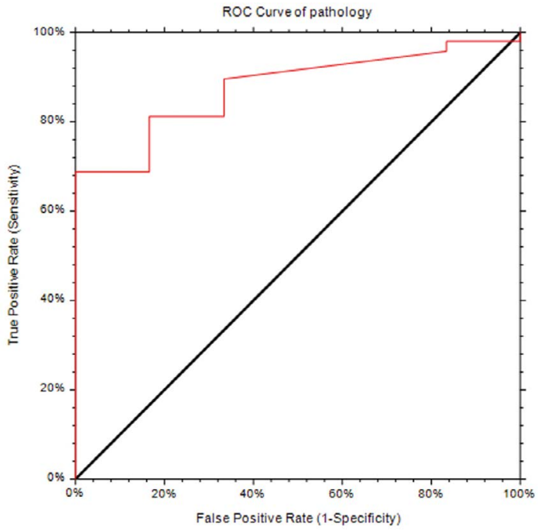

Figure 4. ROC curve for SUV cutoff, AUC = 80% and p-value = 0.002

Regarding [18F]FDG PET/CT; our study showed prominent sensitivity of 84% and specificity of 80% for regional nodal metastases during initial assessment or detection of recurrence. Meanwhile, a study performed by Weber T et al. [12], evaluating the role of [18F]FDG PET/CT for pre-surgical assessment of patients with persistent or recurrent DTC, showed a relatively higher sensitivity (93%) and lower specificity (75%) than our study. However, it is worth mentioning that their study group included only 18 patients who were candidate for cervical re-exploration.

Also, Hempel J et al. [5], who studied 46 DTC patients, concluded a relatively higher sensitivity than our study (88%) and a non-concordant lower specificity (67%). Considering the retrospective nature of their study, beside their dependency on the retrieved original scan reports for clinical decisions, there is a strong limiting element for neutral patients' evaluation and standardized criteria-based diagnosis.

In agreement with our study, close results were obtained from a previous meta-analysis carried out by Kim S et al. [13]; that was performed across 9 studies with 515 patients, aiming at assessing the diagnostic performance of [18F]FDG PET/CT for detection of recurrent and/or metastatic DTC patients. This metanalysis revealed pooled sensitivity and specificity of 84% and 78% respectively.

In the same pace, another meta-analysis done by Caetano R et al. [14] evaluated the accuracy of [18F]FDG PET/CT and [18F]FDG PET/CT for detecting recurrence of DTC where pooled sensitivity showed relatively higher results eliciting 93%, and nearly similar pooled specificity 81%.

Comparing DW-MRI to [18F]FDG PET/CT, our study revealed higher specificity for [18F]FDG PET/CT surpassing DW-MRI with the specificity of 80% and 60% respectively. This was not the same as regards sensitivity which was congruent for both modalities (84%). Meanwhile, Nagamachi S et al. [11] revealed superiority for the capability of [18F]FDG PET/CT for detection of nodal metastasis or recurrence compared to DW-MRI with the sensitivity of 84.2% and 57.6% respectively.

Recently, combined PET and MRI have come into existence as a major hybrid imaging modality. Such modality provided both the quantifiable functional and molecular information through PET combined to the unique tissue characterization of MRI [15].

By attempting to investigate such synergistic diagnostic performance that could be obtained from combined DW-MRI and [18F]FDG PET/CT, our study revealed increased sensitivity that reached 96% compared to 84% when using either DW-MRI or PET/CT alone. However, the specificity (80%) was equivalent to that obtained using [18F]FDG PET/CT alone.

Reliability on different diagnostic imaging-based criteria for PET and DW-MRI may point to the need for assessing their complementary diagnostic role. It may stand behind the higher detection rate that could be achieved using combined modalities, with subsequently higher sensitivity than that obtained in our study. Such opinion was also supported by the notable incidence of disagreement between [18F]FDG PET/CT and DW-MRI which represented 24% of the pathologically proven group with nodal metastases (6 out of 25 patients).

Close sensitivity of 94% was obtained by Hempel J et al. [5], who investigated the diagnostic performance of the combined conventional MRI and PET/CT modalities, however, it is worth mentioning that their study lacks evaluation of MRI diffusion sequences.

Quantitative-based Image Analysis

Regarding DW-MRI ADC cut-off value, in the present study the optimum threshold for the ADC was 1.01×10^{-3} mm²/s with sensitivity, specificity, accuracy, and PPV of 61%, 80%, 68%, and 85% respectively with p-value = 0.001, denoting significance of the applied data.

Kanmaz L et al. [16] had studied the role of DW-MRI in the differentiation of head and neck masses and found that when the ADC value of 1.13×10^{-3} mm²/s or less was used to predict malignancy, the best results were achieved with sensitivity, specificity, accuracy and PPV of 93.33%, 82.35%, 87.5%, and 82.35% respectively.

Another study was carried out to assess the role of the ADC in the differentiation between benign and malignant neck masses held by Salem F et al. [10]. They found that the optimum threshold for the ADC was 1.25×10^{-3} mm²/s, resulting in a sensitivity, specificity, and accuracy of 95.4%, 83.3% and 92% respectively.

According to Razek A. et al [17], which have also studied the role of DW-MRI in cervical lymphadenopathy, if an ADC value of 1.38×10^{-3} mm²/s was used as a threshold value for differentiating malignant from benign lymph nodes, the best results were obtained with an accuracy, sensitivity, specificity, PPV and NPV as 96%, 98%, 88%, 98.5%, and 83.7% respectively.

Many reasons can be related to the large variations between studies on ADC values. For example, the choice of the b values, as a lower b values, increases the signal-to-noise ratio for being in stage but makes the sensitivity to diffusion worse. Also, the choice of the region of interest on ADC maps and the use of sequences that minimize artifacts to make the calculation of the area of interest more accurate are other considerations [18].

Very limited studies have used SUV_{max} cutoff value either for assessment of nodal metastases in DTC. In our study ROC marked SUV_{max} 3.1 as a discriminating diagnostic value with sensitivity, specificity, accuracy, and PPV as 81%, 83%, 81%, and 98% respectively, with significance was noted (p-value = 0.002).

Chong et al. [19] compare the diagnostic performance of [18F]FDG PET/CT versus CT in pre-operative detection of regional nodal metastases from papillary thyroid carcinoma, concluded that better sensitivity for [18F]FDG PET/CT could be achieved when using SUV_{max} 2 as a diagnostic cutoff value exceeding the sensitivity of conventional CT. In agreement with the previous study, Jeong et al. [20] also used SUV_{max} 2.0 as the cutoff value for nodal metastases.

Other authors tried to predict the regional nodal metastatic potentiality in papillary thyroid carcinoma by deducing a cutoff point from the primary tumor itself, where Jung et al [21] marked SUV_{max} 4.6 to be an optimum cutoff point associated with cervical nodal deposits. Lower cutoff point of 2.6 was reported by Byun et al [22]. Variation in deduced cutoffs is likely technically related due to different machines that may influence SUV_{max} values.

Study limitations

The study enrolled a relatively small population of DTC patients. However, the prospective nature of the study together with the mandated pathological verification of the whole group stood behind it. MRI studies lack using of contrast media which may influence its sensitivity. The current study also lacks a direct correlation between TG level and scans findings.

Conclusions

[18F]FDG PET/CT study is a valuable diagnostic modality for the assessment of DTC patients, who are at risk or with suspected recurrent regional nodal metastases with reasonable specificity surpassing DW-MRI. Combined [18F]FDG PET/CT and DW-MRI have synergistic diagnostic performance for nodal metastases detection in DTC, associated with better sensitivity than using a single modality.

Recommendations

Further studies with a larger population may allow detailed per level/compartmental nodal-based analysis. Beside its established role in other head and neck malignancies, PET/MRI should be furtherly investigated in DTC patients considering the combined value that could be obtained from both functional and tissue characterizing techniques. Semi-quantitative and quantitative methods of image analysis are essential and should be standardized to lower inter-observer variability with higher reproducibility while providing a range of values for comparison with other indicators of disease extent and response.

Conflict of interest

Authors have no conflicts of interest and have nothing to disclose.

References

1. Furuya-Kanamori L, Sedrakyan A, Onitilo AA, et al. Differentiated thyroid cancer: millions spent with no tangible gain? Endocr Relat Cancer. 2018; 25(1): 51–57, doi: 10.1530/ERC-17-0397, indexed in Pubmed: 29042396.
2. Schmidbauer B, Menhart K, Hellwig D, et al. Differentiated thyroid cancer-treatment: state of the art. Int J Mol Sci. 2017; 18(6), doi: 10.3390/ijms18061292, indexed in Pubmed: 28629126.
3. Shokoohi A, Berthelet E, Gill S, et al. Treatment for recurrent differentiated thyroid cancer: a canadian population based experience. Cureus. 2020; 12(2): e7122, doi: 10.7759/cureus.7122, indexed in Pubmed: 32257668.
4. Hollenbeak CS, Boltz MM, Schaefer EW, et al. Recurrence of differentiated thyroid cancer in the elderly. Eur J Endocrinol. 2013; 168(4): 549–556, doi: 10.1530/EJE-12-0848, indexed in Pubmed: 23337385.
5. Hempel JM, Kloeckner R, Krick S. Impact of combined FDG-PET/CT and MRI on the detection of local recurrence and nodal metastases in thyroid cancer. Cancer Imaging. 2016; 16(1): 37, doi: 10.1186/s40644-016-0096-y, indexed in Pubmed: 27809936.
6. Papaleontiou M, Haymart MR. New insights in risk stratification of differentiated thyroid cancer. Curr Opin Oncol. 2014; 26(1): 1–7, doi: 10.1097/cco.0000000000000022, indexed in Pubmed: 24285100.
7. Chen Q, Raghavan P, Mukherjee S, et al. Accuracy of MRI for the diagnosis of metastatic cervical lymphadenopathy in patients with thyroid cancer. Radiol Med. 2015; 120(10): 959–966, doi: 10.1007/s11547-014-0474-0, indexed in Pubmed: 25725789.
8. Treglia G, Muoio B, Giovanella L, et al. The role of positron emission tomography and positron emission tomography/computed tomography in thyroid tumours: an overview. Eur Arch Otorhinolaryngol. 2013; 270(6): 1783–1787, doi: 10.1007/s00405-012-2205-2, indexed in Pubmed: 23053387.
9. Platzek I, Beuthien-Baumann B, Schneider M, et al. PET/MRI in head and neck cancer: initial experience. Eur J Nucl Med Mol Imaging. 2013; 40(1): 6–11, doi: 10.1007/s00259-012-2248-z, indexed in Pubmed: 23053322.
10. Salem F, Elshafey R, Elmahalawy M, et al. Apparent diffusion coefficient measurements in the differentiation between benign and malignant neck masses. Egyptian J Radiol Nucl Med. 2014; 45(2): 367–375, doi: 10.1016/j.ejrnm.2014.01.011.
11. Nagamachi S, Wakamatsu H, Kiyohara S, et al. Comparison of diagnostic and prognostic capabilities of 18F-FDG-PET/CT, 131I-scintigraphy, and diffusion-weighted magnetic resonance imaging for postoperative thyroid cancer. Jpn J Radiol. 2011; 29(6): 413–422, doi: 10.1007/s11604-011-0572-z, indexed in Pubmed: 21786097.
12. Weber T, Ohlhauser D, Hillenbrand A, et al. Impact of FDG-PET computed tomography for surgery of recurrent or persistent differentiated thyroid carcinoma. Horm Metab Res. 2012; 44(12): 904–908, doi: 10.1055/s-0032-1316351, indexed in Pubmed: 22791600.
13. Kim SJ, Lee SW, Pak K, et al. Diagnostic performance of PET in thyroid cancer with elevated anti-Tg Ab. Endocr Relat Cancer. 2018; 25(6): 643–652, doi: 10.1530/ERC-17-0341, indexed in Pubmed: 29559552.
14. Caetano R, Bastos C, Oliveira Ide, et al. Accuracy of positron emission tomography and positron emission tomography-CT in the detection of differentiated thyroid cancer recurrence with negative131I whole-body scan results: A meta-analysis. Head & Neck. 2015; 38(2): 316–327, doi: 10.1002/hed.23881.
15. Rosenkrantz AB, Friedman K, Chandarana H, et al. Current Status of Hybrid PET/MRI in Oncologic Imaging. AJR Am J Roentgenol. 2016; 206(1): 162–172, doi: 10.2214/ajr.15.14968.
16. Kanmaz L, Karavas E. The role of diffusion-weighted magnetic resonance imaging in the differentiation of head and neck masses. J Clin Med. 2018; 7(6): 130, doi: 10.3390/jcm7060130, indexed in Pubmed: 29844262.
17. Razek AK, Soliman NY, Elkhamary S, et al. Role of diffusion-weighted MR imaging in cervical lymphadenopathy. Eur Radiol. 2006; 16(7): 1468–1477, doi: 10.1007/s00330-005-0133-x, indexed in Pubmed: 16557366.
18. Perrone A, Guerrisi P, Izzo L, et al. Diffusion-weighted MRI in cervical lymph nodes: differentiation between benign and malignant lesions. Eur J Radiol. 2011; 77(2): 281–286, doi: 10.1016/j.ejrad.2009.07.039, indexed in Pubmed: 19716671.
19. Chong A, Ha JM, Han YH, et al. Preoperative lymph node staging by FDG PET/CT with contrast enhancement for thyroid cancer: a multicenter

study and comparison with neck CT. Clin Exp Otorhinolaryngol. 2017; 10(1): 121–128, doi: 10.21053/ceo.2015.01424, indexed in Pubmed: 27334517.

20. Jeong HS, Baek CH, Son YI, et al. Integrated 18F-FDG PET/CT for the initial evaluation of cervical node level of patients with papillary thyroid carcinoma: comparison with ultrasound and contrast-enhanced CT. Clin Endocrinol (Oxf). 2006; 65(3): 402–407, doi: 10.1111/j.1365-2265.2006.02612.x, indexed in Pubmed: 16918964.
21. Jung Jh, Kim CY, Son SH, et al. Preoperative prediction of cervical lymph node metastasis using primary tumor suvmax on 18F-FDG PET/CT in patients with papillary thyroid carcinoma. PLoS One. 2015; 10(12): e0144152, doi: 10.1371/journal.pone.0144152, indexed in Pubmed: 26636824.
22. Byun BH, Jeong UG, Hong SP, et al. Prediction of central lymph node metastasis from papillary thyroid microcarcinoma by 18F-fluorodeoxyglucose PET/CT and ultrasonography. Ann Nucl Med. 2012; 26(6): 471–477, doi: 10.1007/s12149-012-0594-3, indexed in Pubmed: 22467230.