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FULL PAPER

Real-time intraprocedural ^{18}F -FDG PET/CT-guided biopsy using automated robopsy arm (ARA) in the diagnostic evaluation of thoracic lesions with prior inconclusive biopsy results: initial experience from a tertiary health care centre

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Objective: The aim of this study was to assess the feasibility and appraise the diagnostic utility of real time ^{18}F -FDG PET/CT-guided biopsy under automated robopsy arm (ARA) guidance for the evaluation of thoracic lesions with prior inconclusive biopsy results.

Methods: PET/CT-guided biopsy of thoracic lesions was performed in patients who had at least one previous inconclusive biopsy. A total of 25 patients (male:female—18 males, 7 females; age: range, 13–75; mean, 53.7) were included in this study. All these patients underwent percutaneous needle biopsies under real-time PET/CT guidance using ARA (ROBIO-EX, Perfint healthcare Pvt Ltd, Chennai, India) needle navigation technique. Histopathology and clinical follow-up results were reviewed for assessing the accuracy of procedures.

Results: Adequate representative tissue sample could be retrieved in all the patients. No major procedure-related complications were encountered in any patient. Of the 25 procedures, 21 lesions were positive for malignancy and benign findings were observed in the other 4 lesions on histopathology. None of the patients required further biopsy in arriving at a final diagnosis. Overall diagnostic yield of the procedure was 100%.

Conclusion: Real time ^{18}F -FDG PET/CT guidance for percutaneous biopsies of lung and mediastinal lesions is a feasible technique with potential utility in patients with previous inconclusive biopsy results.

Advances in knowledge: ^{18}F -FDG PET/CT guidance reduces the sampling errors by specifically targeting areas of viability and avoiding necrosis/atelectasis. A navigational tool like ARA is thought to help in accurately targeting these areas.

INTRODUCTION

Conventional imaging (CI) with radiography and CT plays an important role in the preliminary evaluation of a thoracic mass. Characteristic imaging features can often suggest a set of plausible differential diagnoses. However, accurate tissue characterization of the mass is always required as it has a bearing on further management.^{1,2} Also, the advent of personalized and targeted therapeutic options made it more compelling to obtain a detailed histological and immunophenotypic profiling.^{3–5} Utilizing image guidance during

tissue sampling for obtaining optimal tissue specimens is a well-established practice.^{6,7} However, these CI modalities have a few inherent limitations and thus are not infallible.

Thoracic masses are often associated with variable central necrosis and viable tissue may only be noted in the periphery of the lesion.^{5,8,9} CI modalities mainly depict the “form” but not the “functional status” of the tissue visualized and hence cannot accurately differentiate viable tissue from necrosis.⁹ Although contrast enhancement

might partially help determine the optimal site for biopsy, it is not completely accurate. Thus, an ineffectively guided sampling using CI can lead to retrieval of inadequate tissue specimen or an erroneous diagnosis.^{10–12} Sampling errors often delay the diagnosis and institution of treatment to the patient. They are worrisome as they pose medical, financial and psychological burden to the patients and their care givers and are a resource burden to the healthcare system as a whole.^{10,13,14}

¹⁸F-FDG PET/CT has the distinct advantage of metabolic characterization of visualized tissues and thus has a potential to accurately differentiate viable from non-viable tissues.^{15,16} This property of ¹⁸F-FDG PET/CT could reduce inconclusive biopsy results by specifically targeting areas of viability showing ¹⁸F-FDG uptake. Also, added advantage of metabolic characterization by ¹⁸F-FDG PET/CT lies in the fact that it can guide the lesion to be biopsied when more than one lesion is present and that it can identify early pathological changes before obvious morphological changes appear on CI.^{17,18}

Benefits of ¹⁸F-FDG PET/CT in guiding biopsies have been explored recently, but many of these studies were performed utilizing previously acquired PET/CT images to guide the intraprocedural needle placement through visual or software-based fusion.^{19–21} Although this approach is more effective than the conventional technique, it is not devoid of errors due to technical or procedure-related logistics (*e.g.* differences in patient positioning etc).¹⁸

In the present study, we evaluated the diagnostic utility of real-time intraprocedural ¹⁸F-FDG PET/CT guidance for sampling thoracic masses using an automated robopsy arm (ARA) in patients with a prior inconclusive CI-guided needle aspiration or core biopsy result.

MATERIALS AND METHODS

Patients

A total of 25 consecutive patients (18 males and 7 females) with thoracic lesions who were subjected to biopsy under ¹⁸F-FDG PET/CT guidance from December 2014 to June 2016 have been included in this prospective study. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. Informed consent was obtained from all individual participants included in the study. Primary inclusion criteria were the presence of a thoracic mass with history of prior inconclusive image-guided CT/ultrasonography/endobronchial ultrasonography needle aspiration or core biopsy result. The exclusion criteria were as follows: (i) age <12 years, (ii) refusal to provide written informed consent, (iii) abnormal coagulation studies (raised PT, aPTT/INR >1.6) or a platelet count <60,000 mm⁻³, (iv) no FDG uptake in the lesion of concern, (v) inaccessible lesion and (vi) uncooperative patient.

Patient Preparation

Before planning the procedure, potential risks, benefits and available alternatives were discussed with the patients. In all patients,

details of the procedure were explained and written informed consent obtained. Anticoagulant medication was discontinued for at least 4 days and coagulation profile performed within the past 24 h were rechecked for adequacy.

¹⁸F-FDG PET/CT imaging

Patients in whom no prior PET/CT imaging had been done, a diagnostic PET/CT (GE discovery 710, Chicago, IL) was initially performed after administration of 296–370 MBq of ¹⁸F-FDG. Oral or intravenous contrast was administered as clinically indicated. The biopsy procedure was performed in these patients after a time delay of 4–6 h with an intent to reduce the radiation exposure to the operator. In patients with a previous PET/CT study, a lower dose of ¹⁸F-FDG (111–148 MBq) was administered and biopsy procedure was performed, 40–60 min later.

¹⁸F-FDG PET/CT-guided biopsy procedure

¹⁸F-FDG PET/CT images were reviewed prior to procedure and trajectory was planned keeping in consideration the safety, area of maximal FDG avidity, lesion accessibility and relation with the critical structures. Patient positioning (prone/supine/lateral decubitus) was optimized after considering for the depth of the lesion and the planned trajectory. Patients were immobilized in a fixed position using vacuum-assisted patient motion arrester bed during the entire procedure. All the procedures were done under strict aseptic precautions.

A regional single-bed position pre-procedural PET/CT (Pre-PPC) was first acquired including the lesion of interest. Pre-PPC images were then transferred to an ARA for needle guidance (ROBIO-EX, Perfint healthcare Pvt. Ltd, Chennai, India; [Figure 1](#)). The pre-planned trajectory was then executed on the planning console of ARA. A “point of insertion” and a “target point” (a point proximal to the point of maximal FDG avidity) were determined. Attention was paid to mark the “target point” 2 cm proximal from the intended target to accommodate the throw of the automated biopsy gun ([Figure 2](#)). This ARA-assisted procedural plan (ARAPP) was then used to position the robotic biopsy arm in an orientation that corresponds to the planned trajectory.

After determining the incision site which was readily ascertained from the final position of the ARA effector, local anaesthetic was injected. A co-axial cutting cannula with an inner stylet was introduced under ARA guidance. Low-dose check CT (IdCC) was acquired to assess the positioning of the needle. The IdCC images were then fused with ARA-assisted procedural plan images to confirm the position of needle tip at the target point. After confirming the positioning of cannula tip (using intraprocedural PET/CT), automated spring-loaded biopsy gun was introduced through the outer cannula to obtain the histological samples. Operating physician and an assistant stayed inside the PET/CT scanner room during skin preparation, local anaesthesia, skin incision and needle manipulation and stayed out of the room when IdCC images were acquired. At least 2–4 cores of tissue of size 0.5–2 cm could be retrieved during each procedure. Tissues were quickly fixed in 10%

Figure 1. Automated robotics arm.

formalin solution and were sent for histopathological analysis. An immediate post-procedural as well as 2-h post-procedure chest radiograph was acquired to look for any pneumothorax, in all patients. Effective patient immobilization using motion arrester bed and three-dimensional position sensitive pre-calibrated coupling of the ARA with the scanner ensured the reliability of fusing PET images of the PrePPC scan with the subsequent check CT scans.

RESULTS

A total of 25 patients (18 males, 7 females; age range 13–75 years) were included in this study. All the patients had thoracic (lung/mediastinal) mass with at least one prior inconclusive biopsy result.

^{18}F -FDG PET/CT-guided biopsy—procedural aspects

Of the 25 patients, 17 patients (Group A) underwent diagnostic ^{18}F -FDG PET/CT on the same day of the biopsy procedure. In the remaining 8 patients (Group B), 7 patients had a diagnostic ^{18}F -FDG PET/CT within the previous month (range: 5–30 days) and the other patient had it 4 months prior to biopsy. In these 8 patients, regional PET/CT of the thorax was performed prior to the biopsy procedure.

As mentioned prior, the dose of ^{18}F -FDG administered and time to start the biopsy procedure (TTSB) post tracer administration were different between the two groups. The range of doses administered were 222–401 MBq and 118–233 MBq ^{18}F -FDG in the group A and B, respectively. TTSB was in the range of 134–381 min and 84–138 min for the group A and B, respectively. Total procedural time (defined as the time from PrePPC study to post sampling check CT) varied from 15 to 78 min (mean: 41.9 min). A minimum of 3 spot CT images were acquired in each patient. Additional scan(s) were performed to reposition the needle during the procedure when necessary. All the procedures were performed using single action spring loaded automated biopsy gun (18G biopsy needle) and coaxial cutting cannula (16G). None of the patients encountered any complications related to the biopsy procedure except for minimal transient bleeding from the biopsy site in one patient which was self-limiting. No bleeding/haemoptysis were noted in this patient during the subsequent monitoring period. Figures 3 and 4 represent two illustrative cases from the study group.

Histopathological analysis

^{18}F -FDG PET/CT-guided biopsies were successful in obtaining a representative sample in all the patients and were even adequate for immuno-histochemistry profiling. None of the patients required an additional biopsy/further diagnostic evaluation giving a diagnostic yield of 100% (25/25).

On histopathological analysis, 21 cases (84.0%, 21/25) were positive for malignancy and 4 cases (16.0%, 4/25) were consistent with benign aetiology. Of these 21, 12 were non small cell carcinoma (57.1%, 12/21); 5 were lymphoma (23.8%, 5/21); and one each of teratoma, mixed germ cell tumour, sarcomatoid carcinoma and signet ring cell carcinoma. The 4 cases with benign pathology were one each of necrotizing pneumonia, organizing pneumonia, non specific inflammation and tuberculosis.

Follow-up

Among the four patients with benign findings, two patients with pneumonia improved within few weeks of oral antibiotic therapy and follow-up chest radiograph showed resolution of the lung lesions. The patient diagnosed with non-specific inflammation was conservatively managed and follow-up CT scan after 3 months revealed resolution of pleural-based soft tissue lesion. Patient with the diagnosis of pulmonary tuberculosis was sputum negative for AFB and put on antitubercular treatment but later lost to follow-up. All the patients with a diagnosis of malignancy were treated with chemo/radiotherapy/palliative therapy (none of the cases were operable) as per the decision of

Figure 2. Execution of planned biopsy trajectory in ARA console by marking points of insertion and target; (a) trajectory is defined after marking points of insertion and target in the ARA console. (b) ARA effector arm using its four axes oriented to its final position according to the planned trajectory. (c) Using the final position of ARA effector and coaxial cutting cannula inserted through the sterile plastic adapter, site of skin incision is ascertained. (d) After making a small skin incision under local anaesthesia, cannula is inserted till the sampling site. ARA, automated robopsy arm.

treating oncologist. All the patients with benign diagnosis were alive while 11 of the 21 patients with diagnosis of malignancy died of disease. Table 1 summarizes the study, advantage offered by PET/CT guidance in each patient in the study population and their clinical follow-up.

DISCUSSION

The field of image-guided tissue sampling has seen the introduction of several new techniques in the recent years. Advancements in imaging protocols and navigation techniques are showing promise in improving the diagnostic accuracy of these procedures.^{19,22}

Percutaneous transthoracic CT-guided biopsy is the standard of care for the histological evaluation of majority of the thoracic lesions. It is an established technique, which is safe, often well tolerated by the patients and demonstrate diagnostic accuracy higher than 90%.^{2,23} As mentioned previously, CT guidance is not unerring and size of false negative findings can be as high as 26%, varying with size of the lesion biopsied and location.^{5,13,23} This pitfall can also often stem from the fact that anatomical imaging techniques fail to differentiate viable from non viable regions in lesions with significant heterogeneity, a feature commonly noted with thoracic lesions.^{8,9}

Due to its functional nature, ¹⁸F-FDG PET/CT can facilitate accurate retrieval of tissue sample from the (most) metabolically active area within a heterogeneous lesion and thus can reduce false negative biopsy procedures.^{17,18} Utilization of ¹⁸F-FDG

PET/CT for guiding biopsy procedures has significantly evolved over the past decade.

Initially, findings on PET/CT images were used by radiologists for guiding subsequent CT-guided biopsy by visual co-registration.²⁰ Subsequently, software techniques were developed that facilitated co-registration of PET/CT images with intraprocedural CT images.²⁰ These provided objective co-registration and eluded the need for fallible visual registration method. Tatli et al prospectively studied percutaneous biopsies of abdominal masses in 14 patients using fusion of prior PET/CT images on to intraprocedural CT images. They concluded from their initial experience that intraprocedural guidance by software based registration of previous PET/CT images is feasible and particularly may be helpful in cases where the lesion is not clearly demonstrable on CT images.²¹ Subsequently, Purandare et al reported an overall incremental benefit in 47.3% (53/112) patients by incorporating PET/CT information in guiding biopsies using visual or software based fusion techniques.²⁰ Guralnik et al recently retrospectively co-registered the procedural CT images with ¹⁸F-FDG PET/CT images of the 311 patients who had undergone CT-guided FNA of lung lesions.²⁴ They demonstrated that the distance between tip of needle and area with the highest metabolic activity was greater in patients with false negative results. Despite these advantages, potential spatial registration errors may arise while using this technique due to the differences in patient positioning during interventional procedure and PET/CT acquisition which can limit rigid and accurate registration of the studies.^{19,22}

Figure 3. A 62-year-old male with a history of non-contributory CT-guided biopsy of the lung mass in RLL was scheduled for a PET/CT-guided biopsy. Transaxial fused PET/CT and CT images (a, b) showing intense FDG uptake a small medial portion with photopenia in the rest of the mass suggestive of necrosis. Automated robotic arm was utilized in guiding the needle tip to the FDG avid portion as can be visualized in the fused PET/CT and CT images (c, d). Photomicrographs showing necrotic tissue on conventional CT-guided biopsy (e; X100) and adenocarcinoma on tissue specimen obtained through PET/CT-guided biopsy (f; X400). PET/CT guidance was crucial in guiding the biopsy to the metabolically active portion of the disease. RLL, right lower lobe.

More recently, intraprocedural PET/CT guidance technique has been developed where PET/CT was acquired immediately prior to the biopsy and subsequent biopsy procedure was performed on the same scanner. This technique was further enhanced by acquisition of regional PET emission data (single bed position) during the procedure to assuredly confirm the needle placement in most metabolically active area (real time intraprocedural technique).¹⁹ In a retrospective study of 12 patients (14 procedures; bone: 6, soft tissue: 6), Kleaser et al concluded that PET/CT guidance is feasible and especially helpful in evaluating metabolically active lesions with no morphological correlate.²⁵ In their subsequent retrospective review, these authors also described the feasibility of bone biopsies under PET/CT guidance.²⁶ In a

recent large retrospective study of 106 patients by Cornelis et al, the authors utilized intraprocedural technique and reported that PET/CT guidance is safe and effective method with high diagnostic success.²⁷ Similar conclusions were made by Aparici et al.²⁸ However, in contrary to the initial positive reviews, Yokoyama et al reported that PET/CT-guided biopsy has no definite diagnostic advantage of over CT-guided biopsy. In their study of 106 patients with mediastinal tumours, biopsies were performed with ($n = 56$) and without ($n = 50$) registration of prior PET/CT images. This discrepancy in outcome might have stemmed from the differences in type of lesions biopsied (mediastinal lesions alone vs solid lesions of no specific location) in these studies.²⁹

Figure 4. A 70-year-old male with previous history of inconclusive biopsy from right lung mass was scheduled for a PET/CT-guided biopsy. Maximal intensity projection reveals a large heterogeneous area of increased FDG avidity in the right hemithoracic region. Coronal (b) and transaxial fused PET/CT (c) images showing a large mass obliterating the right hemithorax with heterogeneous FDG uptake (predominantly in the peripheral region). Note was made of large central necrotic area with the most metabolically active area in the superior aspect of the mass. Transaxial fused PET/CT image (d) demonstrates the successful needle tip placement in the superior highly metabolically active portion of the mass. Lower panel depicts the photomicrographs showing presence of necrotic tissue alone on the specimen sample from conventional CT-guided biopsy (e; X100) and tumoral cells with focal positivity for cytokeratin immune stain (f; X200) & diffuse positivity for vimentin immune stain (g; X200) on tissue specimen obtained through PET/CT-guided biopsy. Histopathological findings confirmed a diagnosis of sarcomatoid carcinoma.

In our study, study design had definite superiority over previous studies that explored the real time intraprocedural technique. Head-on comparison of CT alone and PET/CT-guided techniques by performing both techniques in any given patient is universally restrained due to ethical considerations. Also, paucity of well equipped PET/CT centres limits the generalizability of this technique and questions its potential to replace CT alone technique. Hence, by choosing a more selective patient population which had at least one prior inconclusive biopsy results, we targeted a more viable area of interest. By additional utilization of ARA arm for accurate needle navigation/targeting and vacuum assisted patient arrester bed for minimization of patient motion, we explored the feasibility to further enhance the efficiency of the real time intraprocedural technique. Although size of the study population was small, we anticipate this enhanced diagnostic accuracy(if any) to persevere in to larger population studies.

PET/CT-guided interventions are expected to result in significant radiation exposure to the personnel and this quantity is

a function of time spent by the personnel in close proximity to the patient during the procedure. Ryan *et al*, in their study involving 12 patients who underwent PET/CT-guided procedures, attempted to measure the radiation exposure to the personnel and determined a median effective dose of 0.02 mSv to the primary operator, 0.01 mSv to the nurse anaesthetist and 0.02 mSv to the radiology technologist.³⁰ The use of ARA arm for needle navigation is thought to reduce the radiation exposure to the personnel by reducing the time spent in proximity to the patient, although no such attempt to measure the exposure was done in the present study.

Metabolic biopsy, like any other procedure, is not devoid of limitations. Primary drawback is the increased radiation dose to the patients and personnel, although an attempt to quantitate the exposure was not done in this study. High cost involved with this technique is another limitation. Administration of as low an activity of ¹⁸F-FDG as needed that will provide an acceptable image quality can reduce both patient and personnel radiation

Table 1. Demographic characteristics and clinical follow-up of the patients enrolled in the study

No	Age	Sex	Lesion characteristics	Previous Bx/FNA	Previous HPE result	FDG PET/CT findings	HPE result of PET-guided biopsy	Remarks	Treatment received	Follow-up
1	49	M	Heterogeneous left superior mediastinal mass	CT guided	Necrotic material	Intense uptake in a peripheral region with large central necrosis	Teratoma	Targeting the viable peripheral rim facilitated technical success	CCT + XRT	Alive
2	70	M	Heterogeneous mass replacing left lung	USG guided	Necrotic material	Peripheral uptake in the superior portion of the lesion	Sarcomatoid Carcinoma	Metabolically active peripheral tissue in the superior portion could be accurately targeted	CCT	Died
3	65	M	Heterogeneous mass in left upper lobe	USG guided EBUS guided	Necrotic material No malignant cells	Uptake limited to posterosuperomedial and inferomedial aspects of the lesion	NSCLC, NOS	Posterosuperomedial aspect of the mass was targeted to obtain viable tissue	CCT + XRT	Alive
4	75	M	Heterogeneous mass in right lower lobe	EBUS guided	Chronic inflammation	Patchy heterogeneous uptake with multiple areas of relative photopenia	NSCLC, NOS	Inferior portion of the lesion showing lesser heterogeneity of FDG uptake was targeted	Palliative	Died
5	62	M	Heterogeneous right hilar mass	CT guided	Necrotic material	Uptake was limited to a crescentic superomedial portion of lesion	Adenocarcinoma	Accurate targeting of the viable superomedial portion facilitated technical success	Palliative	Died
6	52	M	Heterogeneous mass in right middle lobe	USG guided EBUS guided	Infective pathology; fungal No malignant cells	Heterogeneous FDG uptake in large interspersed areas of non avidity	Necrotizing Pneumonia	Biopsy from even the avid portion suggested pneumonia; follow-up confirmed the HPR result	Antibiotic Therapy	Alive; complete resolution of Mass
7	35	F	Ill defined heterogeneous right hilar lesion	CT guided	No malignant cells	Heterogeneous FDG uptake with interspersed areas of necrosis	Signet ring cell carcinoma	Uniformly and intensely metabolically active associated pleural lesion was targeted to procure viable tumour tissue	CCT	Alive; discontinued treatment due to poor tolerance
8	72	M	Heterogeneous mass in right upper lobe	CT guided	Inflammation	Interspersed areas of necrosis with relatively uniform uptake in superior portion	Adenocarcinoma	Sampling of the uniformly FDG avid superior portion was facilitated	CCT	Died
9	58	M	Peripherally enhancing soft tissue mass	USG guided	Necrotic material	Intense uptake was limited to periporions of superior and inferior portions of the lesion	NSCLC, NOS	Targeting of the uniformly metabolically active tissue in superior portion was facilitated	CCT	Died

(Continued)

Table 1. (Continued)

No	Age	Sex	Lesion characteristics	Previous Bx/FNA	Previous HPE result	FDG PET/CT findings	HPE result of PET-guided biopsy	Remarks	Treatment received	Follow-up
10	13	F	Homogenous right hilar soft tissue mass with distal lung collapse	EBUS guided	No malignant cells	Uptake in portion of the right hilar lesion and absent uptake in the collapsed lung and rest of the lesion	DLBCL ¹	Metabolically active portion of the homogenous lesion was targeted	CCT	Alive
11	58	F	Two heterogeneous lesions in bilateral lower lobes	CT guided	Inconclusive ? NET	Uniform uptake in RLL lesion while heterogeneous uptake was noted in LLL lesion (previously biopsied)	Tuberculosis	PET facilitated targeting uniformly metabolically active lesion in RLL	ATT	Alive; significant symptomatic improvement
12	45	F	Large heterogeneous mass in the left hemithorax	EBUS guided EBUS guided EBUS guided	No malignant cells No malignant cells No malignant cells	Intense uptake limited to superolateral portion of the lesion	Plasmablastic lymphoma	Metabolically active tissue in the superolateral portion could be accurately targeted	CCT	Died
13	25	M	Heterogeneous anterior mediastinal mass	USG guided	No malignant cells	Heterogeneous FDG uptake with interspersed areas of necrosis	Lymphoblastic Lymphoma	Targeting of the most metabolically active region was facilitated	CCT	Alive
14	70	M	Spiculated heterogeneous mass in LUL	CT guided	Inflammation	Intense uptake in a peripheral region with large central necrosis	Squamous cell carcinoma	Inferior portion of the lesion showing maximal intensity of FDG uptake was targeted	CCT	Died
15	63	M	Heterogeneous pleural based soft tissue lesion	CT guided CT guided	Inconclusive Organizing Inflammation	Intense uptake in the lesion with large central necrosis	Inflammation	Biopsy from even the avid portion suggested inflammation	Antibiotic therapy + conservative management	Alive; significant symptomatic improvement
16	51	F	Heterogeneous soft tissue mass	USG guided	Inconclusive	Uptake was uniform and intense in the superior portion of lesion	NSCLC, NOS	Targeting of the uniformly metabolically active viable superior portion was facilitated	CCT	Alive
17	49	M	Heterogeneous mass in left upper lobe	CT guided	Necrotic material	Patchy heterogeneous uptake with multiple areas of relative photopenia	Squamous cell carcinoma	Superior portion of the mass devoid of heterogeneity was targeted	CCT	Died
18	65	M	Heterogeneous mass in left lower lobe	CT guided	Inconclusive	Uptake more in the lateral aspect of the mass	Pneumonia, organizing	Lateral aspect of the mass could be targeted to obtain viable tissue	Antibiotic therapy	Alive; complete resolution of the mass

(Continued)

Table 1. (Continued)

No	Age	Sex	Lesion characteristics	Previous Bx/FNA	Previous HPE result	FDG PET/CT findings	HPE result of PET-guided biopsy	Remarks	Treatment received	Follow-up
19	66	M	Heterogeneous mass in left parahilar region with associated collapse	CT guided	No malignant cells	Patchy heterogeneous uptake with multiple areas of relative photopenia with absent uptake in the collapsed region	Adenocarcinoma	Targeting of superior portion of the lesion showing lesser heterogeneity of uptake was facilitated	Palliative	Died
20	23	F	Heterogeneous mass involving superior and anterior mediastinum	USG guided	Neoplasm	Heterogeneous FDG uptake with multiple areas of interspersed non avidity	DLBCL	Sampling of the FDG avid anterior portion resulted in technical success	CCT	Alive
21	47	F	Heterogeneous mass involving right upper and middle lobes	EBUS guided	Inconclusive	FDG uptake in rim of the mass with large central necrotic core with more pronounced FDG avidity in medial aspect	Hodgkin's disease	Targeting of the FDG avid medial portion was done	CCT	Alive
22	72	M	Heterogeneous mass in right lower lobe	CT guided	Inconclusive	Intense uptake was limited to superior portion with multiple small areas of necrosis	NSCLC, NOS	Uniformly metabolically active tissue in superior portion could be targeted	Palliative	Died
23	70	M	Large peripherally enhancing mass in the right hemithorax	CT guided	Inconclusive	Uptake in rim of the mass with large central necrotic core with prominent FDG uptake in superior, medial and inferomedial aspects	Squamous cell carcinoma	Targeting of FDG avid inferolateral portion of the lesion was done	CCT	Died
24	73	M	Heterogeneous lesion in right upper lobe	USG guided	Inconclusive	Uniform uptake in the superior aspect as compared to the inferior aspect with necrotic regions	Adenocarcinoma	PET facilitated targeting of superior aspect with relatively uniform FDG uptake	CCT	Alive
25	15	M	Large heterogeneous peripherally enhancing mass in the left hemithorax	CT guided	Necrotic material	Uptake in the rim and few interspersed foci of uptake in anterior, superior and medial aspects of the mass with large central necrotic area	Mixed germ cell tumour	Metabolically active tissue in the anterior portion could be accurately targeted	CCT	Alive

ATT, antitubercular therapy; Bx, biopsy; CCT, chemotherapy; DLBCL, diffuse large B cell lymphoma; EBUS, endobronchial ultrasonography; FNA, fine needle aspiration; NOS, not otherwise specified; NSCLC, non-small cell lung carcinoma; RLL, right lower lobe; USG, ultrasonography; XRT, external radiotherapy.

dose. Studies to standardize the same may be needed. Recently, researchers explored the utility of low-dose and ultra-low-dose CT protocols and demonstrated that significant reduction in radiation dose can be achieved with no negative impact on the diagnostic rates of the biopsy procedures.^{31,32} Thus, increased radiation burden to the patient can be partially addressed by incorporation of these novel CT protocols and reducing the activity of ¹⁸F-FDG administered to the bare minimum required. Also, integration of robotic arm assistance can lower the procedural time and thus can reduce the radiation dose to personnel with simultaneous increment in diagnostic accuracy.^{19,22,33}

Limited availability of PET centres and modern equipment may restrict the widespread application of this technique in remote

sectors. However, whenever available, due consideration is justified for utilization of this technique, especially in the context of a previous failed biopsy procedure.

Real time ¹⁸F-FDG PET/CT guidance for percutaneous biopsies of thoracic lesions under ARA guidance is a feasible technique with potential utility in patients with previous inconclusive biopsy results. Furthermore, ARA guidance proves to be promising in accurate targeting of the metabolically active tissue and thus avoiding unsuccessful biopsy procedures.

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