The Role of PET-CT in Lymphoma Staging and Monitoring: Insights from Saudi Cancer Care Facilities, Comparative Analysis, Clinical Guidelines and Recommendations and Future Prospects

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ABSTRACT

This study takes a closer look at the vital role of PET-CT in the staging and observation of lymphoma in the Saudi cancer care centers. PET-CT is an integral part in the management of lymphoma with advantages in diagnosis, staging, and assessment of the response to therapy. The utility of getting more specific information about metabolic activity that forms a basis for better clinical decision-making and prognostication makes it useful; however, its limitations must be put against the knowledge of heterogeneity in FDG uptake in various types of lymphomas to optimize its utility in practice. PET-CT has emerged to be an important imaging procedure because it provides metabolic and anatomical data, thus having a significantly higher accuracy for diagnosis and staging as well as therapeutic assessment than conventional techniques have. Issues in variability and

limitations of post-treatment surveillance are presented. Clinical trials and regional studies also reveal insights in this aspect- the evolving role of PET-CT in Saudi Arabia, alongside recommendations on its standard application within oncology centers to ensure positive results on patients. In summary, the role of lymphoma staging and monitoring lies in guiding treatment decisions, making predictions about outcomes, and enabling timely adjustments to therapy. Advances in imaging technology, particularly PET/CT, have dramatically changed the lymphoma management landscape and provide more accurate staging as well as effective monitoring of the response to treatment.

Keywords: PET-CT, Lymphoma, Staging, Monitoring, FDG Uptake, Saudi Cancer Care, Extranodal Lymphoma, Imaging Modalities.

1. Introduction

The role of PET-CT in the management of lymphoma is multi-faceted and involves its application for diagnostic, staging, evaluation of treatment, and even prognosis. PET-CT has really revolutionized the way management of lymphoma should be approached, mainly by allowing for the possibility of combining both anatomical and functional imaging for the accurate assessment of the disease. Increased sensitivity and specificity in the diagnosis and staging of all types of lymphomas is one of the main benefits of PET-CT. For example, a number of research studies reported that PET-CT was significantly more superior to conventional CT for metabolic activity detection in lymphomas, especially at extranodal sites and in the case of indolent lymphomas (Metser et al., 2017; El‐Galaly et al., 2015; Zytoon et al., 2020).

The integration of functional imaging provides a more holistic understanding of the disease because it can identify changes in metabolic activity that correlate with tumor burden and response to treatment (El‐Galaly et al., 2018; Zou et al., 2017). This is highly relevant in the context of extranodal lymphomas, in which PET-CT has been proven to be highly accurate in the detection of primary involvement, for instance, in central nervous system lymphomas (Zou et al., 2017; Moon et al., 2013). More importantly, PET-CT plays an essential role in the evaluation of treatment. Interim and end-of-treatment PET-CT scans are used to measure metabolic response to therapy, which in turn may affect management. In the case of marginal zone lymphomas, for instance, post-treatment CMR is strongly associated with improved progression-free survival rates (Park et al., 2017). This puts emphasis on the prognostic value of PET-CT, as it can pick residual disease that might not appear apparent on conventional imaging methods (El‐Galaly et al., 2015; Park et al., 2017).

However, application of PET-CT also poses many challenges. There exists variation in the uptake of FDG among different types of lymphomas. As such, interpretation becomes very challenging especially in low-grade and T-cell non-Hodgkin lymphomas as the avidity for FDG may not be strong enough (Moon et al., 2013; Wu

et al., 2010). Furthermore, whereas PET-CT is essential in initial staging and treatment follow-up, its role in post-treatment surveillance remains controversial, with some experts advising against routine use, mainly due to fear of radiation exposure and a risk of false negatives, particularly in certain types of lymphomas (Farghaly et al., 2015; Mansour, 2010).

The staging and monitoring of lymphoma are crucial parts of effective management for this heterogeneous group of malignancies. It accurately stages and informs the decision for the treatment of a patient and predicts the outcomes and adjusts the therapeutic strategy on the basis of response to therapy. One of the primary reasons staging is important is that it determines the extent of disease involvement, which directly affects treatment options. For example, the International Prognostic Index (IPI) stratifies patients into risk categories by stage, age, and performance status in order to guide therapy selection (Perry et al., 2007;. Recent staging of this disease has much been made possible with sophisticated imaging, especially with the 18F-FDG PET/CT, where some diseases could not be distinguished or were not evident to be appreciated on ordinary clinical examination, including both nodal and extranodal (Wu et al., 2010; Zhou et al., 2014). For this, some lymphomas particularly the MALT lymphomas could easily be missed even the use of PET/CT for determination of the number and places involved changes the appropriate therapy plan (Alinari et al., 2006).

Monitoring in and after treatment is as important because it offers an assessment of therapeutic effectiveness and residual disease. Interim PET scans may give an early sense of the response to treatment, so the clinician can alter the treatment. For example, a complete metabolic response on PET scans is associated with a better prognosis in patients with several types of lymphoma, including DLBCL (Perry et al., 2007; Karam et al., 2006). On the other hand, continued metabolic activity may indicate failure of treatment and thus require reassessment of the treatment strategy (Buck et al., 2006). Second, long-term follow-up of the progression or recurrence of the disease should be monitored. By continuous imaging and clinical checkups, it is more readily identifiable at an early stage of relapse, indicating the use of salvage therapies that can be administered to patients for an improved prognosis (Sato et al., 2021). PET/CT has been found to have improved the detection of relapses during follow-up as compared with conventional imaging; this improves early intervention (Wu et al., 2010; Zhou et al., 2014).

The context of cancer care in Saudi Arabia is determined by a combination of increasing cancer incidence, challenges within the healthcare system, and changes in treatment modalities, including the use of advanced imaging technologies such as PET-CT. Increasing burden of cancer in the country among specific demographics necessitates a strong healthcare response to enhance early detection, treatment, and patient outcomes. Cancer incidence in Saudi Arabia has been on the rise, with specific cases of increased incidence in particular types, such as breast, colorectal, and prostate cancers. For example, breast cancer is responsible for a large percentage of cancer cases among women; it accounts for 29% of all cancers reported in this population Abdel-Salam et al. (2020). This trend is made worse by lifestyle factors, like obesity and diabetes, prevalent in the Saudi population. In fact, it was reported

that about 33% of Saudis were obese, and this contributes to the increased incidence of certain cancers (Althubiti & Eldein, 2018). This further complicates the detection process of cancers like colorectal cancer, where more patients are diagnosed at late stages, resulting in poorer survival rates than in other countries (Al‐Sanea et al., 2015).

The Saudi health system has invested hugely to develop cancer care for accessible quality services to citizens and expatriates alike (Wazqar et al., 2017). However, there are still challenges in terms of the integration of health services and the training of oncology professionals (Wazqar et al., 2017). There is also an advancement in EMRs, which may facilitate better data management and tracking of patients, thereby affecting treatment pathways, including the use of PET-CT for staging and monitoring (Otaybi et al., 2022). The imaging provided by PET-CT is very crucial in cancer management in Saudi Arabia in that it enables accurate staging of malignancies and can monitor the response to the treatment. It is vital because PET-CT offers metabolic activity detection, which gives an early identification of the residual disease. This has been significant in a context where late presentations are often presented in healthcare settings (Wazqar et al., 2017). As the health care system continues to grow, PET-CT in routine cancer care is increasingly incorporated as it may enhance diagnostic accuracy and efficiency in treatment, thus better patient outcomes.

2. Overview of Lymphoma

It belongs to a heterogeneous group of haematological malignancies classified broadly into two major entities: Hodgkin lymphoma (HL) and NHL. Each category includes specific subsets, each having its inherent clinical features, histologic attributes, and approaches to the treatment. The major feature of Hodgkin Lymphoma (HL) is the presence of Reed-Sternberg cells. The classification by the World Health Organization divides HL into two main types: classical Hodgkin lymphoma and nodular lymphocyte-predominant Hodgkin lymphoma.

Table 1: The subtypes of Classical Hodgkin Lymphoma (cHL) and Non-Hodgkin Lymphoma (NHL).

Lymphoma Type	Subtype	Characteristics	Citation
Classical Hodgkin Lymphoma (cHL)	Nodular Sclerosis	Most common subtype; associated with mediastinal lymphadenopathy.	Togo et al. (2011)
	Mixed Cellularity	Varied cellular composition; often seen in older adults.	Togo et al. (2011)
	Lymphocyte-Rich	Less common; typically has a better prognosis.	Togo et al. (2011)
	Lymphocyte-Depleted	Rarest subtype; associated with a poorer prognosis.	Togo et al. (2011)
Non-Hodgkin	Diffuse Large B-	Most prevalent subtype of NHL;	Garza-

Lymphoma (NHL)	Cell Lymphoma (DLBCL)	aggressive but potentially curable.	Morales et al. (2023)
	Follicular Lymphoma	Slow-growing B-cell lymphoma; second most common subtype; often presents with advanced-stage disease.	Garza-Morales et al. (2023)
	Burkitt Lymphoma	Highly aggressive B-cell lymphoma; common in children; associated with MYC gene translocation.	Cadavid et al. (2017)
	Mantle Cell Lymphoma (MCL)	Rare, aggressive B-cell lymphoma; often diagnosed at an advanced stage.	Thomas et al. (2019)
	Peripheral T-Cell Lymphoma (PTCL)	Diverse group of aggressive T-cell lymphomas; less common; challenging to treat.	Valli et al. (2010)

Diagnosing and managing lymphoma entails several clinical challenges that will have great implications for patients. It is a complicated disease in which the various presentations occur with different limits of the resources available to diagnose.

3. Challenges in Diagnosing

The similarity in morphological features is one of the main sources of difficulty while diagnosing lymphoma. For example, plasmablastic lymphoma, a subtype of diffuse large B-cell lymphoma, is hard to differentiate from multiple myeloma because of overlapping histologic features Kmira (2023). This makes it even more challenging in less resourceful pathology environments, where diagnosis may rely heavily on morphology. Indeed, in such settings, differential diagnoses between Burkitt lymphoma and lymphoblastic lymphoma are particularly challenging because BL and LBL can closely mimic each other in many clinical features, including the presence of lymphadenopathy and mediastinal masses (El‐Mallawany et al., 2017).

In addition, the FNA cytology may be problematic in the diagnosis of Hodgkin lymphoma because the sample obtained often is inadequate for a precise classification, especially in cases of composite lymphomas when more than one histologic type coexists (Das et al., 2016).Even in core needle biopsies, lack of architectural analysis can be a problem in diagnosing it correctly as it is usually difficult to diagnose in cases of low-grade non-Hodgkin lymphomas (Mutlu et al., 2023).

Clinical Presentation Variation:

Lymphomas can be very nonspecific in presentation and may mimic so many conditions that sometimes the diagnosis is delayed. For example, primary pulmonary MALT lymphoma may be a non-resolving pneumonia that requires a high index of suspicion to diagnose (Iftikhar et al., 2017). Lymphomas that spread to other sites, like skeletal muscle, may be confused with sarcoma and metastatic disease, which makes diagnosis challenging (Hatem & Bogusz, 2016).

Challenges of Treatment:

Management of Lymphoma Once diagnosed, the management of lymphomas is quite complex and varies depending on the type. Among all these cancers, non-Hodgkin lymphomas are the most common. This category of cancer has various histological types with different treatment protocols and prognosis (Patel et al., 2021). Comorbidities at diagnosis or advanced disease make the decision of treatment a complex one. Additionally, lymphomas usually require a multidisciplinary team with oncologists, pathologists, and radiologists to manage patients in the best way possible. However, coordination of care among the specialties can sometimes be difficult, especially in resource-poor settings where specialized care can be lacking at times (El-Mallawany et al., 2017; Patel et al., 2021).

Table 2: Comparative Analysis of PET-CT in Global vs. Saudi Contexts.

Aspect	Global Trends	Saudi Context	Reference
Availability	Widely available in developed nations with high-density imaging centers in urban and some rural areas.	Predominantly available in urban centers like Riyadh and Jeddah. Rural areas face significant limitations in access.	Alshagrawi, 2023.
Cost Implications	Covered by national health services or insurance systems in countries like the UK, USA, and Germany.	Free healthcare but advanced imaging like PET-CT often incurs additional costs, creating disparities in rural areas.	Karantanis, 2012.
Clinical Guidelines	NCCN and ESMO guidelines widely implemented for consistent staging and treatment planning.	Adoption of international guidelines ongoing, but adherence varies across healthcare facilities in Saudi Arabia.	Fujiwara et al., 2011.
Training and Expertise	Countries like the USA and UK have well-established training programs for radiologists and nuclear medicine specialists.	Saudi Arabia is actively expanding training initiatives, but expertise gaps remain, especially in rural facilities.	Geiger et al., 2022.

Prognostic Uncertainty:

Another challenging issue that might come up due to particular subtypes of lymphomas is the prognostic significance. Some genetic mutations or cytogenetic abnormalities might have implications for response to therapies and prognosis but would not be done in all clinics (Yonese et al., 2018). The comparison of PET-CT with other imaging modalities in the context of lymphoma diagnosis and management highlights its better accuracy and effectiveness in numerous clinical scenarios. PET-CT, especially with 18F-FDG, has emerged as a crucial tool in the

staging and follow-up of lymphoma by providing both metabolic and anatomical information.

Sensitivity and Specificity:

PET-CT has been much more sensitive and specific than the conventional methods of CT and MRI. One such research study reported that when diagnosing lymphoma, the sensitivity of PET-CT was 92%, but the specificity was 92.2%, which is much higher than the conventional anatomical imaging techniques Waqar et al. (2023). This sensitivity can detect metabolic activity in lymphomas, which otherwise passes through routine CT scans.

Role in staging and treatment response:

PET-CT is especially valuable in staging lymphomas and for the evaluation of response to therapy. Evidence exists that, besides these applications, it could also be more sensitive than CECT in the follow-up evaluation of response, with 100% sensitivity and specificity for PET-CT against sensitivity at 61.1% for CECT during treatment (Ahmed et al., 2020). This could lead to timely adjustment of treatment plans when there is an observed metabolic response of lymphoma to treatment.

Extranodal Involvement:

PET-CT is best with the diagnosis of extranodal involvement, a problem usually met with by other imaging agents. PET-CT diagnostics in the cases of mucosa-associated lymphoid tissue are reported to be more successful, even more than with classical methods, for diagnosing the disease and staging the cancer ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023). Moreover, PET-CT demonstrated high sensitivity for the detection of primary brain involvement in CNS lymphomas, and can be a useful non-invasive diagnostic approach when MRI cannot be performed ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023).

Comparison to MRI:

Even though PET-CT is a sensitive imaging modality, advances in technology, such as PET-MRI, are on the way to potentially challenge PET-CT. It has been proven that PET-MRI decreases the exposure to radiation greatly, but it still maintains good-quality morphological information alongside the PET data (Grueneisen et al., 2016). Some research has demonstrated PET-MRI to be comparable in its ability to diagnose as PET-CT in conditions like lymphoma and bone involvement (Picardi et al., 2021). The decision would then depend on the clinical situation at hand and whether radiation exposure needs to be considered, especially in children.

Limitation of PET-CT:

Although PET-CT possesses many advantages, there is a disadvantage of PET-CT. This modality varies with the histologic type of lymphoma, so some are less FDG avid, and detection rate may be affected (Wang et al., 2018). For example, MALT lymphoma has not been as evident on PET-CT as other more aggressive lymphomas such as DLBCL or Burkitt lymphoma, which are highly FDG avid in most patients (Wang et al., 2018; Mayerhoefer et al., 2014).

4. Role of PET-CT in Lymphoma Staging

PET-CT heavily depends on lymphoma staging and has significant benefits compared to other traditional techniques. It is a tool with high diagnostic accuracy due to a synergy of anatomical details produced by computed tomography (CT) and metabolic information from positron emission tomography (PET).

High Sensitivity and Specificity:

In many studies, PET-CT is established to have more significant sensitivity and specificity as compared to standard CT and MRI in staging patients with lymphoma. The metabolic activities of lymphoma could be nonvisible on computed tomography, but they can be detected in patients' PET-CT images with a more significant accuracy of staging as noted by Wang et al., (2018), and Mandava et al., (2019). For example, it is observed that PET-CT highly increased the sensitivity for nodal and extranodal disease, which has critical significance in determining a relevant treatment strategy (Wang et al., 2018).

Extranodal Involvement:

The area where the rest of the imaging will face problems in identification can easily be identified with the use of PET-CT. PET-CT has shown to be very helpful in the staging of extranodal lymphomas like gastrointestinal tract or cutaneous lymphomas, especially if enhancing metabolic activity sites suggest spreading of the disease ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023; Zhou et al., 2014). This will also be important for the comprehensive staging and treatment planning because it allows for targeted radiation therapy with more thoughtful clinical decision making ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023).

Alteration of Staging Decision:

Staging can be altered by PET-CT that is not visible by conventional imaging. For instance, studies found that PET-CT resulted in the upstaging of almost 50% of the patients with NK/T-cell lymphomas because it better identifies lesions that uptake FDG (Wu et al., 2010). Upstaging is considerably important as it may lead to variations in treatment that would involve more aggressive therapies or include radiation in treatment.

Monitoring of Treatment Response:

PET-CT is especially useful not only at initial staging but in monitoring the treatment response. Since PET-CT information regarding metabolism is thus available, clinicians can observe how well a lymphoma would be responding to the administered therapy and can, therefore, be very crucial at times for timely adjustments to the treatment plans (Mandava et al., 2019; Cunha et al., 2022). Ability

to visualize a change in metabolic activity assists in the distinction of residual disease from posttreatment change in order to proceed with additional management.

Other Imaging Modalities Comparison:

PET-CT is set as the reference modality when it comes to staging, but not entirely effective as other types may not favor its use appropriately. Take, for example, some indolent lymphomas, whose FDG uptake may be so low thereby lowering the sensitivity of the PET-CT in their staging (Abdulqadhr et al., 2011). In such situations, additional information may be provided through other imaging modalities such as diffusion-weighted MRI especially in the case of lymphomas with variable FDG avidity (Albano et al., 2019; Regacini et al., 2015). However, PET-CT remains the gold standard imaging modality in aggressive lymphomas like DLBCL and Hodgkin lymphoma, with high sensitivity and specificity (Wang et al., 2018; Albano et al., 2019).

More Sensitive Disease Detection:

One of the main advantages is the sensitivity to active disease that PET-CT provides when applied in the staging of lymphoma. For instance, PET-CT has been shown to detect advanced-stage disease, stages III-IV, in 100% cases, whereas the same might detect early-stage disease, stages I-II, in approximately 42.3% cases Stecco et al. (2015). This is often seen because early-stage lymphomas are generally smaller and have lower metabolic activity that can result in underdiagnosis when diagnosed based only on conventional imaging techniques.

Table 3: PET-CT Diagnostic Benefits in Lymphoma.

Diagnostic Benefit	Details	Study Reference
Enhanced Sensitivity	PET-CT is highly sensitive, identifying extranodal lymphoma and FDG-avid lesions invisible on CT or MRI.	Weber et al., 2021.
Staging Accuracy	Improves staging by identifying occult lesions, upstaging 31% of patients with early-stage lymphoma.	Katsura et al., 2015.
Differentiation of Inflammation	Differentiates post-treatment inflammatory changes from residual disease using metabolic activity data.	Minamimoto et al., 2010.
Prognostic Value	PET-CT findings, such as complete metabolic response (CMR), correlate with better progression-free survival.	Zou et al., 2017.
Impact on Treatment Planning	Alters treatment strategies in 50% of cases where PET-CT detects previously undiagnosed extranodal sites.	Zhou et al., 2014.

Treatment Planning Impact

This will determine the appropriate staging for treatment. If the PET-CT scan is advanced, then the clinician might opt for more aggressive therapy regimens, such as chemotherapy and radiation therapy, because the condition of the disease has become widespread (Yoo, 2022). When the PET-CT indicated that it was at an early stage, the treatment is not intense and avoids all side effects that come with aggressive therapy.

Detection of Extranodal Involvement PET-CT is highly sensitive to the detection of extranodal involvement, one of the hallmark features of advanced-stage lymphoma. Extrandal sites often change staging and hence management of the disease. For example, PET-CT is highly sensitive for diagnosis and staging of MALT lymphoma and other extranodal lymphomas in addition to important information not clearly obtained on CT ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023; Othman et al., 2019). It is also necessary in overall staging and planning for therapy.

Poor detection in Early Stages:

Although PET-CT has several advantages, it is unable to emphasize early-stage lymphomas, especially in indolent subtypes, which shows low FDG avidity. In such cases, the PET-CT imaging cannot clearly depict the picture of the disease and may sometimes misclassify the stage of disease (Wang et al., 2018; Maccioni et al., 2021). In short, although PET-CT is the standard for almost all aggressive lymphomas, whole-body MRI can complement it in most cases with indolent lymphomas characterized by low levels of metabolic activity (Metser et al., 2017).

Clinical Implication:

The outcomes of the proper staging achieved through the use of PET-CT are really significant. Lack of the accurate staging of a lymphoma, results in ineffective treatment; therefore, these patients face worse outcomes. For example, one study showed that PET-CT upstaged lymphoma in 31% of patients, largely in the early stages, and modified treatment strategies in 25% of cases based on findings obtained from PET-CT (Katsura et al., 2015). It, therefore, underlines the importance of incorporating PET-CT into routine staging protocols to ensure optimal management of lymphoma patients.

Numerous investigations and clinical trials have testified for the role of PET-CT in the diagnosis and management of lymphoma. The investigations highlight the value of PET-CT to ensure correct staging of disease, hence guiding the treatments and also monitoring the treatments' responses.

5. PET-CT Effectiveness: Clinical studies and Clinical trials

One of the most critical studies conducted was in King Khalid University Hospital and King Fahad Medical City Hospital concerning barriers to the participation of Saudi nationals in cancer clinical trials. This multi-center study consisted of 244 patients, and it highlighted the issues that might affect participation in clinical trials, including those involving sophisticated imaging modalities such as PET-CT Almutairi et al. (2016). The results indicated a better informed and educated patient about the benefits of clinical studies and may recruit more participants for studies to research the effectiveness of PET-CT in the treatment of lymphoma.

Role of PET-CT in Extranodal Lymphoma:

Studies have shown that PET-CT is useful in the diagnosis and staging of extranodal lymphomas as these are usually more challenging to assess when using non-PET-CT imagings. One published study in the Egyptian Journal of Hospital Medicine proved the success of PET-CT in managing extranodal lymphomas, as it helped in detecting changes in metabolic activity that can be a surrogate marker for the tumor's location and response ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023). This is quite crucial in the Saudi perspective because there are some prevalent subtypes of lymphomas such as NK/T-cell lymphoma.

Comparative Studies:

A systematic review had considered the role of PET-CT in diagnosis and staging of NK/T-cell lymphoma, with positive results on its diagnostic importance (Zhou et al., 2014). The review pointed out that PET-CT may drastically alter staging and hence treatment strategies, which would be an important step for optimal patient outcomes in a population where these lymphomas are endemic. But still, the role of PET-CT in this procedure is not well established, thus calling for future research.

Case Studies Which Have Demonstrated the Potentiality of PET-CT:

It has been proven in a case study of pulmonary mucosa-associated lymphoid tissue (MALT) lymphoma that PET-CT diagnosed more lesions than the conventional CT, which consequently resulted in upstaging and better clinical management (Albano et al., 2017). This finding is in line with general literature, as PET-CT has been proven to increase the detection of lymphoma, especially when the conventional imaging fails to detect lesions.

Challenges and Opportunities:

Although PET-CT has been proved to be successful, still some challenge remains in carrying out clinical trials within the broader context of Saudi Arabia. "Knowledge and attitudes toward clinical trials" study demonstrated that awareness and knowledge regarding clinical research were one of the main factors influencing the involvement of this research study (Al-Rawashdeh et al., 2019; Al-Tannir et al., 2016). More clinical trials could be validated in order to prove the role of PET-CT in the management of lymphoma.

6. PET-CT in Monitoring Treatment Response

PET-CT can monitor the response of the treatment in patients with lymphoma as it offers great insight into metabolic activity combined with anatomical changes occurring during and after therapy. PET-CT has been used heavily and validated as a very accurate modality for response assessment of the treatment, for prediction of the outcome, and also in deciding on the management.

Early Response Assessment:

Probably, the most critical applications of PET-CT in managing lymphomas would be the assessment of response during interim studies. Reports show that intermediate results can actually predict outcomes at final assessment after few cycles of

chemotherapy. This may be true as brought about from a meta-analysis that proved that in the lymphoma-afflicted patient and therefore, which was subjected to immunotherapy the good outcome of interim PET-CT survivor predictor, thus by the time the response could be evaluated Kiamanesh et al. (2022). Therefore, it will aid in highlighting the window of opportunity available before the clinician for selecting the patients' treatment should be altered according to the metabolic response.

Prognostic Value:

The finding of PET-CT has prognostic value since well presented. In patients with Burkitt lymphoma, based on interim and post-treatment PET-CT, there has been the ability to predict response to treatment. Positive scans were associated with a high risk of progression, as documented by Wei et al. in 2015. While for marginal zone lymphomas, the improved PFS rates are observed with the CMR post-treatment in association with PET-CT, as documented by Park et al. (2017). This adds further significance to the application of PET-CT for not only response assessment at treatment but also for prognosis stratification.

Follow up Treatment Response:

This is best at the follow-up of the response to treatment because of visualization of changes in metabolic activity. For instance, PET-CT has been found reliable in the evaluation of MALT lymphoma in being able to visualize the change in uptake of FDG, which means there is living tumour present ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023). Therefore, it is able to devise further treatments either to be continued or changed based on the type of metabolic activity that can be visualized.

Difference between Residual Disease and Treatment Effect:

One of the difficulties with the treatment of lymphoma is that the doctor ought to be able to tell between residual disease and inflammatory changes that are observed following treatment. In this regard, PET-CT aids in this because it is useful in distinguishing between living tumor tissue and inflammatory changes which result from treatment (Minamimoto et al., 2010). Timing of PET-CT scans is significant because, for instance, if done too early after radiotherapy, one will get false positives due to inflammation. The best time for evaluation is 8-12 weeks post-therapy, as recommended by Minamimoto et al. (2010).

Limitations and Consideration:

PET-CT is very powerful but not without limitation. Some subtypes of lymphoma have been reported to have low sensitivity, including the indolent lymphomas with low FDG avidity (Ömür et al., 2014). The clinical context must always be taken into account and interpreted cautiously with the result of PET-CT; false positives are likely to occur here, caused by inflammatory processes, which have no relation to the lymphoma (London et al., 2014). So, proper understanding and treatment plans therefore call for collaboration between oncologists, radiologists, and pathologists.

Standardization of PET-CT Protocols Quality along with consistency in imaging applied practice is achieved in this concern standardization of PET-CT protocols. Technical along with clinical guidelines issued for their observance as presented in this concern by a multibio-disciplinary expert group is believed to uphold quality care as well as compare in different centers Beyer et al. (2011). This comes to hold more significance in Saudi Arabia in its developed implementation of PET-CT into practice.

7. Clinical Guidelines and Recommendations

In most cancers, including lymphoma, the use of PET-CT in assessment, monitoring, and surveillance is recommended by NCCN guidelines (Piciu et al., 2020). It is slowly being adopted by the oncology centers in Saudi Arabia for clinical practice. It can be done at the initial assessment of lymphoma to form the basis for the assessment of the disease spread for the planning of management.

Studies and Epidemiological Research

Studies in Saudi Arabia have revealed the incidence rate and patterns of malignant lymphoma, which is an indication that methods of diagnosis as well as treatment measures ought to be implemented (Elasbali et al., 2018). Lymphomas are actually confirmed to be among the top cancers in that area; hence, proper protocols should be established in clinical practice with PET-CT (Alzahrani et al., 2022 and Elasbali et al., 2018). It is only through routine clinical practice that the patient outcome is enhanced.

Clinical Trials and Local Experience:

The studies in local premises have been functional in showing that PET-CT can be used as an assessment of treatment response, as well as disease activity in patients with lymphomas. For example, as one such study reports, staging in 31% of patients was changed by the process, mostly those in the early stage of lymphoma, so their treatment programs were changed appropriately (Katsura et al., 2015). All such studies reflect how PET-CT help in taking decisions at hospitals and there is a need for setting protocols for its optimization.

Challenges and Future Directions:

Challenges on the adoption of PET-CT protocols at general levels pose challenges to all oncology centers in Saudi Arabia. Some factors that may influence the adoption of the service include the availability of technology, education level of the health personnel, and awareness among the people about the importance of PET-CT (Alzahrani et al., 2022; Al-Qahtani et al., 2020). Continued efforts in standardising PET-CT protocols plus ongoing education and training amongst healthcare providers should improve the quality of cancer care delivery in the region.

8. Insights from Saudi Cancer Care Facilities

The number of PET-CT in Cancer Care Centers in Saudi Arabia has been rising with the increasing recognition of the importance of PET-CT in oncology, especially for

diagnosis and management of lymphoma and other malignancies. Specific data about the prevalence of PET-CT facilities in various cancer care centers are somewhat limited.

Increased Access to PET-CT:

It appears PET-CTs are gaining more availability and prominence within the larger tertiary care centers and specialty centers for oncology within the country. The development of the structure has been part of broader undertakings to improve services in the management of cancer, one of the contributing causes of the disease growing in the country, as depicted by Jamal (2023). Similarly, Alshammary et al., 2020). If better diagnostic precision and better treatment planning are to occur, then the imaging tools such as PET-CT would have to be integrated.

Regional Variations:

Even though PET-CT is available in almost all tertiary hospitals, in reality, regional variation is that which exists in its access. The chances of possessing PET-CT units are more in the urban places like Riyadh and Jeddah than in rural places. PET-CT resources are less accessible in some rural settings where fewer resources are provided to state-of-the-art imaging techniques. This will also have an impact on the quick diagnosis and treatment of cancer in this patient population, such as staging and evaluation of their overall response to therapy for those who need PET-CT (Alshagrawi, 2023).

Influence of National Cancer Initiatives:

The government of Saudi Arabia has established several cancer control programs aimed at developing the infrastructures of care, and among these PET-CT facility is also there. The National Cancer Registry has been developed; their improvements in data collection and reporting improve the determination of burden regarding allocation of resources (Ghazwani, 2022; Bawazir et al., 2019). This will expand the count of centers that will utilize the use of PET-CT technology.

Clinical Practice Guidelines and Recommendations:

Most of the clinical practice guidelines from organizations such as National Comprehensive Cancer Network recommend PET-CT at staging, in follow up to monitor treatment response of numerous cancers, such as lymphoma (Al-Dawsari & Amra, 2016). Therefore, the future direction is to apply this with an increase in applying such clinical practice guidelines into daily oncology practices across the oncology centers of Saudi.

Future Directions:

The burden of cancer in Saudi Arabia will manifold by 2030, and therefore, the demand for advanced imaging techniques such as PET-CT will be more (Deja, 2023). In this regard, there is an urgent need to develop availability of PET-CT

centers in all regions of the country, especially in the un-served areas. Besides that, the health workers should be educated to interpret PET-CT scans so that adequate value can be gained from the technology in cancer management. In support of such initiatives, as well as technological advancement, the development of clinical practices has increased the support Saudi Arabia's health infrastructures do in assimilating PET-CT into the continuum of lymphoma care. Such technology integrates to improve oncology diagnostics, treatment, and outcome.

Development of Advanced Imaging Facilities:

Saudi Arabia has invested heavily in the healthcare infrastructures, mainly in major cities such as Riyadh and Jeddah. There are now universal high-end imaging facilities such as PET-CT. This guarantees the establishment of specialized cancer centers and provision with PET-CT technology, affords the capacity for proper disease management, which involves acute staging and observation of the patients with lymphoma (Fujiwara et al., 2011, Vassilakopoulos et al. 2015). Their existence is vital in evidencing-based practice to have the administration of care concerning lymphoma.

There are national and international guidelines, including those of the National Comprehensive Cancer Network (NCCN) and the European Society for Medical Oncology (ESMO), that have approved the use of PET-CT in clinical practice. They play a vital role in evidencing-based practice to have the administration of care concerning lymphoma. There are national and international guidelines, including those of the National Comprehensive Cancer Network (NCCN) and the European Society for Medical Oncology (ESMO), that have approved the use of PET-CT in clinical practice. The organizations mentioned above have the following recommendations on the utility of PET-CT in staging all types of lymphomas, in the assessment of response to treatment, and in follow-up: (Ora et al., 2022; Juweid et al., 2021). In Saudi Arabia, these guidelines are very important to standardize care and have the best evidence for the treatment of patients.

Training and Education

In the health industry, education of health staff in Saudi Arabia should include training on high-technology imaging systems. The radiologists, oncologists, and nuclear medicine experts should continually have medical and technical skills to interpret PET-CTs. These will ensure proper usage of PET-CT for lymphoma management and even accurate diagnosis and treatment prescription (Ghazwani, 2022).

Research and Clinical Trials:

Saudi Arabia has been comparably active in research toward cancer, and some study on the effectiveness of PET-CT in the treatment process of patients with lymphoma exists. Clinical trials about PET-CT in both staging and follow-up of or response to the treatment open up the way forward for expanding evidence over the use of PET-CT (Li et al., 2016; Bodet-Milin et al., 2012). These research efforts will improve the management of lymphoma and contribute to refining protocols and guidelines regarding PET-CT utilization in clinical practice.

Multidisciplinary Approach:

A multidisciplinary approach by oncologists, radiologists, pathologists, and nuclear medicine specialists, PET-CT should come to be integrated in lymphoma care. Such is an essential foundation to correct interpretations of PET-CT as well as a sound choice based on complete evaluation for disease status. Vassilakopoulos et al. (2015); Juweid et al. (2021). Tumor boards and case discussions build from the said multidisciplinary approach. And that is the manner in which patients will receive their appropriately tailored plans of treatment.

Challenges Overcome:

This is a little better, but still has the challenge of equitable access to PET-CT in regions in Saudi Arabia. PET-CT is mainly available in cities rather than rural areas. The expansion of PET-CT in underserved areas is essential in delivering comprehensive care to all cancer patients (Bodet-Milin et al., 2012; Sato et al., 2010). Public education on the benefits of PET-CT may also boost access and usage opportunities among patients.

The integration of PET-CT in the care of lymphoma in Saudi Arabia exposes it to a lot of unique challenges on issues of cost, accessibility, and expertise. Such factors are essential in determining effective PET-CT use in oncology settings.

Cost of PET-CT:

One of the main problems with PET-CT is that it costs a great deal, rendering it unavailable to many patients. In most cases, health insurance will not wholly cover a PET-CT scan. This means a patient, as well as healthcare workers, will suffer from monetary burdens (Karantanis et al., 2012). This is quite devastating in a healthcare system whose government provides free health care, yet advanced imaging technologies such as PET-CT might still incur additional costs that are not universally accessible to patients (Tyrovolas et al., 2020). This would lead to unequal access, especially for those from the rural areas or of a low socioeconomic status.

Access-related Problems:

Access to PET-CT centers is also a problem in itself. The major cities of Saudi Arabia, Riyadh, and Jeddah, have PET-CT units, but in the rural and remote areas, there are no such facilities available (Alfaqeeh et al., 2017). This geographical imbalance may also delay diagnosis and treatment of patients living in remote regions as they would have to travel long distances to access PET-CT services (Alfaqeeh et al., 2017). The limited numbers of PET-CT machines present in the country would also give a patient long waiting times to get scanning, which complicates managing the patients.

Expertise and Training:

The appropriate utilization of PET-CT in clinical practice is also related to the availability of professionals who are appropriately qualified and can interpret the images. It is recognized that in Saudi Arabia, there is a need for constant education and training of healthcare personnel on the proper use of PET-CT in oncology (Karantanis et al., 2012). Lymphoma patients may not fully receive benefits of optimum PET-CT use since service providers might lack awareness regarding the indications, limitations, and interpretations of PET-CT. In general, a deficiency in well-trained professionals contributes to the underutilization of PET-CT in the treatment of lymphomas, as perceived by Almaqhawi (2023).

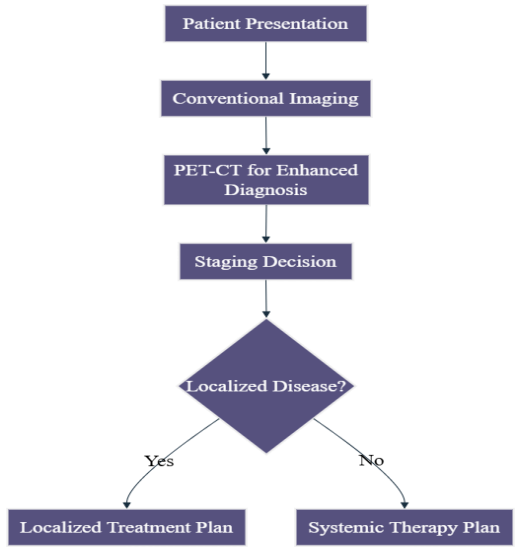

Figure 1: Role of PET-CT in Lymphoma Staging. This flowchart outlines the role of PET-CT in enhancing lymphoma staging. PET-CT contributes critical metabolic and anatomical insights, which guide the distinction between localized and systemic disease, influencing treatment strategies.

Public awareness and Acceptance:

It's therefore very important to have public awareness on the use of PET-CT and its application in the management of cancer so as to be able to integrate this technology into clinical practice. As observed by Tyrovolas et al. (2020), most members of the Saudi community are ignorant of advanced imaging techniques and their role in cancer management. This lack of public education is practically synonymous with a large proportion of patients who might have been dissuaded from accessing PET-CT services.

Regulatory and Infrastructure Barriers:

Somewhat, the other barriers will include some legislation and enhanced existing infrastructure that will eventually hinder the incorporation of PET-CT. Securing new imaging technology can take time owing to the complicated process which, in fact, may even delay the establishment of a PET-CT center in specific region (Almaqhawi, 2023). Such PET-CT imaging becomes dynamic in clinical practice and health care only when the existing infrastructure in health care is improved.

9. Comparative Analysis: Global and Regional Trends

Use of PET-CT in management of lymphoma in Saudi Arabia is continually evolving. Similar to many other countries, it presents some unique characteristics and challenges in its adoption. This paper will focus on a comparison of PET-CT use in Saudi Arabia versus other countries. It covers the areas such as availability, clinical guidelines, and outcomes.

Availability of PET-CT Facilities:

As such, PET-CT facilities are limited to some major metropolitan cities such as Riyadh and Jeddah, where advanced cancer care is closer towards the patient's end. This is similar to many developed countries, where PET-CT is commonly available in specialized cancer centers Li et al. (2016). Conversely, PET-CT use, whereas commonly integrated into oncologic routines in the United States and Germany, is still beset by issues of their presence in rural areas across the Saudi kingdom, a hindrance to equal service in both regions (Ahmed et al., 2020; Adams & Kwee, 2016).

Clinical Guidelines and Protocols:

Adopted recently, like random clinical pointers such as those from the National Comprehensive Cancer Network (NCCN) and the European Society for Medical Oncology (ESMO), Saudi Arabia now incorporated that PET-CT is highly recommended for staging and treatment response assessment for lymphomas, as from recent works by Fujiwara et al. (2011). This is consistent with practices in other countries, where PET-CT is considered the gold standard for these purposes. But whereas the extent of implementation among them varies, such that for a country like Saudi Arabia with less established health care than others, strict adherence by patients to prescribed protocols maybe less strong, as witnessed in some other studies elsewhere (Wu et al., 2010).

Research and Evidence Base:

Research on the effectiveness of PET-CT in the management of lymphoma is on the rise in Saudi Arabia, and research has shown its applicability in staging and in assessing response to treatment (Moon et al., 2013; Li et al., 2013). But, perhaps, the volume of research conducted might not be as large as in countries with longer

histories of PET-CT use, such as the United States or European nations, where many studies have established the prognostic value of PET-CT in different subtypes of lymphomas (Al-Qahtani, 2023). In Saudi Arabia, the level of confidence physicians has when it comes to using PET-CT may also be influenced by this.

Cost and Economic Factors:

The cost of PET-CT scans can be a barrier to access in Saudi Arabia, similar to challenges faced in other countries. Although healthcare is largely provided free of charge in Saudi Arabia, the high costs associated with advanced imaging technologies can limit their availability (Pan et al., 2020). However, nations with more established healthcare financing models may have broader coverage for PET-CT so that it is applied for routine clinical use (Mansour, 2010). This can be an economic determinant affecting the accessibility of the procedure; however, PET-CT has a socioeconomic influence on such Saudi patients, especially on those who cannot afford it.

Table 4: PET-CT Role in Treatment Monitoring.

Role	Details	Reference
Interim Monitoring	PET-CT scans after a few chemotherapy cycles predict outcomes; metabolic response guides therapy changes.	Kiamanesh et al., 2022.
Prognostic Marker	CMR on PET-CT post-treatment correlates with higher survival rates, guiding post-therapy follow-ups.	Park et al., 2017.
Residual Disease Detection	Accurately identifies residual tumor burden, outperforming CT in distinguishing between active disease and fibrosis.	El-Haddad et al., 2015.
Early Detection of Progression	Identifies relapse or refractory disease earlier than conventional imaging by detecting metabolic changes.	Mandava et al., 2019.
Impact on Long-Term Outcomes	Modifies treatment in ~25% of cases based on interim and final PET-CT findings, improving survival metrics.	Alzahrani et al., 2022.

Training and Experience:

The implementation of PET-CT in the treatment of lymphoma must be done by experienced staff who can interpret the PET-CT scans correctly. There is acknowledged need in Saudi Arabia to continue education and training by healthcare providers regarding the appropriate use of PET-CT (Geiger et al., 2022). This challenge, however exists in other countries, yet the level of training varies. More advanced training programs and more readily available resources for healthcare professionals within a country that has well-established PET-CT programs will provide better quality care overall (Lee et al., 2021).

Outcomes and Effectiveness:

Evidence suggests very clearly that the use of PET-CT dramatically improves the accuracy of staging and treatment response in lymphomas and may have a better clinical outcome (Alhowail, 2024). This was similarly reported in Saudi Arabia

where PET-CT changes treatment plans and improves prognostic stratifications (Almaqhawi, 2023). Nonetheless, the total overall patient outcome is still under consideration because, compared with the countries where a lot of data are available on long-term outcome assessments related to PET-CT, they remain small for now.

Several regional studies and data have been carried out in Saudi Arabia regarding the treatment outcomes related to PET-CT use in lymphoma management. These studies give a clue about the efficacy of PET-CT in staging, monitoring response to treatment, and predicting the outcome in the patient, which gives an overview of its use in clinical practice.

Efficiency of PET-CT in the Management of Lymphoma:

A study published in the *Egyptian Journal of Hospital Medicine* highlighted the role of PET-CT in managing extranodal lymphoma as effective in identifying metabolic activity changes, which is used as a surrogate marker for location of the tumor and for evaluation of response to treatment. "Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome" 2023. This work agrees with the fact that diagnostic accuracy and treatment planning are greatly improved in lymphoma patients by PET-CT.

Comparative Analysis of Imaging Modalities:

Research studies comparing PET-CT with conventional imaging techniques have shown that PET-CT is superior in assessing treatment response. For example, a study pointed out that PET-CT had a higher positive predictive value for detecting residual disease compared to CT alone, especially in aggressive non-Hodgkin lymphoma (NHL) and Hodgkin lymphoma (HL) (El-Haddad et al., 2015). This finding is consistent with international data, which underscores the role of PET-CT in clinical decision-making.

Prognostic Implication of Intermediate PET-CT:

Several studies have documented the prognostic value of interim PET-CT in lymphoma treatment. For instance, in a study involving peripheral T-cell lymphoma, patients who achieved negativity on interim PET-CT had significantly better PFS and OS compared to those with positive interim scans (Jung et al., 2015). This finding emphasizes the role of PET-CT in directing the intensity of treatment and improving patient outcomes.

Regional Epidemiological Trends:

A comprehensive study on the survival and epidemiological trends of lymphomas in Saudi Arabia reported that the most common subtypes were diffuse large B-cell lymphoma (DLBCL), classical Hodgkin lymphoma (cHL), and follicular lymphoma (FL) (Alzahrani et al., 2022). The study also noted that treatment outcomes varied based on the subtype, with DLBCL showing a particular response to PET-CT-guided treatment strategies. This regional data puts into perspective how PET-CT is used in the local health setting.

Limitations and Future Directions:

While the studies indicate benefits for PET-CT in lymphoma management, challenges remain. A significant challenge is to access PET-CT facilities countrywide. A study demonstrated that despite improvements in cancer care, disparities in access to high technologies, such as PET-CT, exist; they are more evident in rural areas (Alfaqeeh et al., 2017). Balancing these disparities will therefore help optimize the use of PET-CT in the care of lymphoma.

Some of the global best practices that can be enhanced by facilities in Saudi Arabia may include comprehensive management, engagement and evidence-based treatment interventions in the framework of holistic care to improve the outcomes for patients as well as make the healthcare delivery system very efficient.

The primary lesson from global practices relates to guideline-concordant therapy. Research has shown that a high percentage of patients in areas such as Sub-Saharan Africa do not receive treatment that adheres to the established guidelines because of inadequate diagnostic work-up and sub-classification of lymphoma types (Mezger et al., 2023). This means that Saudi facilities should ensure that their diagnostic processes are robust and that treatment protocols are strictly adhered to base on lymphoma subtype. The International Lymphoma Radiation Oncology Group has created guidelines that maximize radiotherapy treatment, which could be of great benefit to Saudi practitioners to adopt, especially in the reduction of exposure to healthy tissues during treatment (Eich, 2023).

Table 5: Challenges in PET-CT Utilization in Saudi Arabia.

Challenge	Description	Reference
Accessibility	Limited number of PET-CT facilities in rural areas results in delayed diagnosis and treatment.	Alfaqeeh et al., 2017.
Cost Implications	High operational costs of PET-CT lead to financial strain despite government healthcare coverage.	Tyrovolas et al., 2020.
Expertise Gap	Insufficient numbers of trained radiologists and nuclear medicine specialists, especially outside major cities.	Almaqhawi, 2023.
Public Awareness	Limited understanding among patients about PET-CT's benefits, delaying acceptance and utilization.	Tyrovolas et al., 2020.
Standardization Issues	Lack of universal adoption of clinical guidelines leads to inconsistencies in PET-CT use across facilities.	Wu et al., 2010.

In addition, patient-reported outcome measures and self-management interventions can empower patients and encourage them to engage in their care. A study of the Lymphoma InterVEntion (LIVE) program indicates that the use of self-management can increase patient participation in treatment and decrease the demand for healthcare services (Arts et al., 2017). This is more relevant because of the rise in the number of survivors of lymphoma, and such interventions should be available in a manner that will not overstretch healthcare services.

Long-term follow-up care is another important area where Saudi centers can draw lessons from the international community. Evidence indicates that patients with lymphoma have different supportive care needs at different points in their disease trajectory, and thus there is a need for localized survivorship care strategies (Chen et al., 2022). Customizing follow-up care to meet those needs can help significantly enhance the quality of life of the patient after treatment. Indeed, one of the innovative approaches in patient management includes the use of advanced technologies such as machine learning for outcome prediction in pediatric lymphoma cases (Zheng, 2024). Such technologies offer Saudi facilities an opportunity to enhance their predictive abilities concerning the treatment outcomes, and hence personalize care plans.

Importantly, comprehensive geriatric assessments are important for all older patients receiving high-dose chemotherapy and autologous stem cell transplantation. Such a course of action ensures treatment decisions are made in consideration of all the patient's health issues and comorbidities, which is critical to optimizing outcomes in these very sensitive populations (Lahoud et al., 2015).

10. Future Prospects

The development of PET-CT technology promises much promise for improvement in the management of lymphoma through better diagnosis, monitoring of treatment, and results in patients. Some significant areas of further development, as the field of oncology continues to progress, will be identified to improve care in lymphomas. One of the first points would be the integration of advanced imaging techniques and protocols for enhancement of diagnostic accuracy in the management of PET-CT in lymphoma. Recent studies have shown that PET-CT is very useful in the detection of extra-nodal involvement in lymphomas, which is important for staging and treatment planning ("Extra-nodal Involvement in Adult Lymphomas, Experience, and Outcome", 2023). More precise localization of tumors and their metabolic activity can be achieved by refining the imaging protocols and using advanced algorithms, thus guiding radiotherapy planning more effectively (Weber et al., 2021). Moreover, the applicability of reduced scan times with preserved image quality has been established, which allows for higher patient throughput and lower doses of radiation (Weber et al., 2021).

Appropriateness criteria for the application of FDG PET-CT in oncology are updated regularly, and this is associated with the demand for an individualized imaging approach dependent on the characteristics of patients and their diseases (Agrawal & Rangarajan, 2015). This is further supported by registries like the National Oncologic PET Registry, which captures data regarding how PET-CT influences decisions regarding the management of treatment (Metser et al., 2017). This can be utilized by clinicians to optimize PET-CT use in lymphoma management so that the right imaging for a given clinical scenario is used for patients.

Monitoring treatment response is another important role of PET-CT. It has been proven that in aggressive lymphoma types, quantitative measurements of metabolic response using FDG PET in the very early phase can provide relevant prognostic information, and it may be modified to have better outcomes of the patients (Okuyucu et al., 2018). Furthermore, through the Lugano classification, emphasis is placed on functional imaging for assessing treatment response and thus has solidified a place for PET-CT in routine lymphoma management (Yoo, 2022).

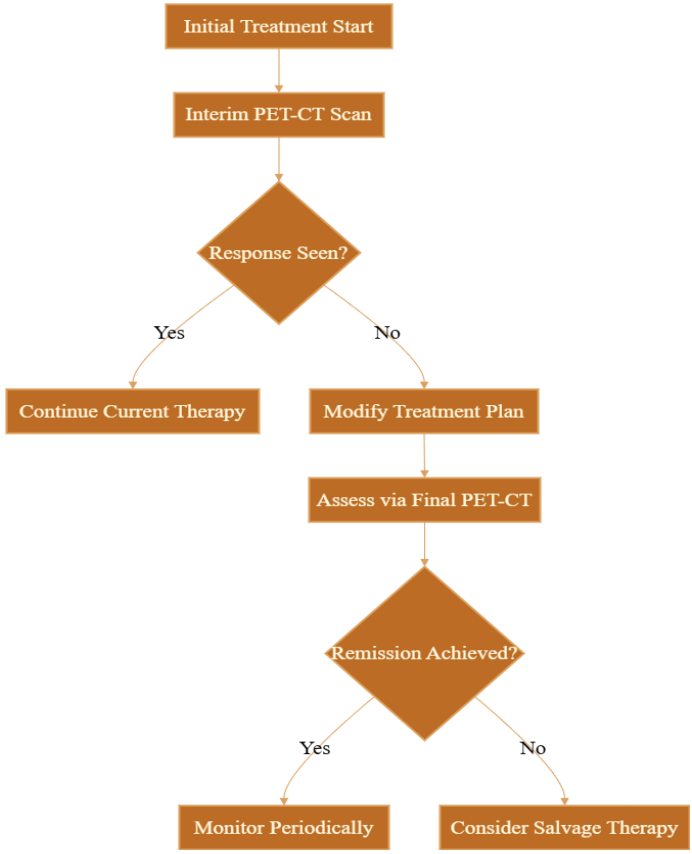

Figure 2: PET-CT in Treatment Monitoring. This flowchart demonstrates the role of PET-CT in monitoring lymphoma treatment. Interim and final PET-CT scans help clinicians assess therapeutic responses and guide decisions for continuing, modifying, or escalating treatment strategies.

The next promising area for the evolution of PET-CT technology is the development of new radiotracers. Like emerging applications, the example potential of Ga-FAPI-04 offers some excitement since it would serve as a broad-spectrum tumor imaging agent-the limitations being those arising from orthodox FDG PET-CT (Qiu et al., 2021). Development and validation of such agents could advance PET-CT diagnostic capabilities to improve detection of low-grade lymphomas that take up little FDG (Elourimi et al., 2021). It is the introduction of AI and machine learning into the

imaging with PET-CT that is bound to change the management of lymphoma. AI plays role in the interpretation of PET-CT image in improving the accuracy of diagnosis and reducing false positives (Pantiora et al., 2016). Furthermore, AI-based algorithms will permit the development of complete-body attenuation maps which optimize imaging protocols and reduce radiations, without compromising the efficacy of their diagnosis (Teimoorisichani et al., 2022).

Make patient's treatment effective and accessible. There are several aspects that should be targeted-the incorporation of advanced nursing roles, adoption of value-based care systems, and the use of telehealth. Advances and innovations in cancer care in Saudi Arabia. The most promising advances are those in the integration of ANPs into the healthcare system. The role of ANPs is known to play a pivotal part in bringing about patient-centered care within healthcare facilities. Qualitative research noted that ANPs can easily integrate into the healthcare delivery model if, for example, the culture barriers are addressed along with changing healthcare professionals' perceptions regarding ANPs (Banaser et al., 2021). This is aligned with Saudi Ministry of Health's Vision 2030, emphasizing the integration of more holistic and patient-centered healthcare approaches (Banaser et al., 2021). Indeed, ANP empowerment enables Saudi healthcare facilities to strengthen patient management, decrease the waiting time for care and improve quality.

As an addition, the value-based care transformation from traditional models is gaining ground in Saudi Arabia. The SHARP group, Saudi Oncology Health Economics Expert Group, recommended value-based procurement agreements stressing the effectiveness and value of treatments, and not simply their price (Alkhudair et al., 2021). This will contribute to reducing the increasing costs of cancer care, while at the same time ensuring that patients receive high-quality, effective treatments for their specific conditions. Such agreements will allow better resource allocation and improvement in outcome of patients in healthcare.

There are tremendous opportunities to improve telehealth. Prior studies conducted prior to the covid-19 evidenced positive correlation of telemedicine with the enhanced access of patients to medical services and lower rates of appointment no-shows (Al-Mana, 2024). The widespread support for telehealth among healthcare providers indicates its potential to improve cancer care delivery for patients who live in remote areas and may find it challenging to access specialist care (Al-Mana, 2024). Widening telehealth’s in the Saudi health systems would, thereby, assure timely consultations and follow-ups for patients with treatment regimens. Another area of improvement can be in public health campaigns that will raise awareness of cancer and preventive measures. For instance, most, actually two-third of knowledge on cancer prevention is derived from media sources rather than health professionals' sources (Ravichandran et al., 2011). Such healthcare authorities have made their public informed on when to diagnose earlier and much better outcomes in treatment by using these media platforms to enlighten the public on the realities of cancer risks, means of prevention, and detection.

Finally, the initiation of standardized cancer management protocols in the country as encouraged by the Saudi Oncology Pharmacy Assembly will enable uniform standards in care practices across regions (Alsuhebany, 2024). Such protocols must be specific about the management of cancer-associated complications such as thromboembolism, which is the most frequent among cancer patients (AlSheef et al., 2023). In this way, Saudi Arabia could standardize care practice and quality improve in that regard for cancer patients by ensuring that healthcare providers go along with it.

Abbreviations

PET-CT: Positron Emission Tomography-Computed Tomography

FDG: Fluorodeoxyglucose

CT: Computed Tomography

MRI: Magnetic Resonance Imaging

HL: Hodgkin Lymphoma

NHL: Non-Hodgkin Lymphoma

CMR: Complete Metabolic Response

PFS: Progression-Free Survival

Conclusion

PET-CT has completely changed the management of lymphoma, providing unparalleled accuracy in staging, assessment of response to treatment, and prognostication. Its use in Saudi Arabia reflects both its potential and challenges. Although PET-CT offers critical advantages in detecting metabolic activity and extra nodal involvement, its optimal use requires addressing regional disparities in access and expertise. By following the standardized protocols along with multidisciplinary collaboration, PET-CT can effectively improve the prognosis of diagnosis as well as treatment of the lymphoma condition and ensure better patient outcome in Saudi Arabia. PET-CT has been more recognized in the management of oncology patients, especially in the management of lymphoma in Saudi Arabia, thus setting proper protocols and guidelines. There is a need for protocols in the standardization of PET-CT across the different oncology centers to ensure uniform and proper usage of PET-CT. PET-CT is used as an important tool for distinguishing between the early and late stages of lymphoma and significantly impinges on treatment decisions and, most importantly, patient management. It offers a less superficial view on the history of the disease by showing its metabolic and anatomical states together.

Conflict of Interest

The authors declare they don’t have any conflicts of interest, in the form of financial, personal, or otherwise.

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Author contributions

The original draft was prepared by the first author and corresponding authors reviewed and supervisor the manuscript. All authors also reviewed and involved in the data collection for manuscript and gave approval for submission it to journal and publication.

Acknowledgement

Authors express their gratitude towards to National Comprehensive Cancer Network (NCCN) and the European Society for Medical Oncology (ESMO), Saudi Arabia. Authors also thankful to clinical practice guidelines and their recommendations for cancer patients.

Ethical Approval

Not Applicable

REFERENCES

Mohamed, E., Abdelhamid, W., Diab, W., & Gaber, M. (2023). Extra-nodal involvement in adult lymphomas, experience, and outcome. The Egyptian Journal of Hospital Medicine, 93(1), 7735-7739. https://doi.org/10.21608/ejhm.2023.329207

Abdel-Salam, D., Mohamed, R., Alyousef, H., ALMASOUD, W., Alanzi, M., Mubarak, A., … & Osman, D. (2020). <p>perceived barriers and awareness of mammography screening among saudi women attending primary health centers</p>. Risk Management and Healthcare Policy, Volume 13, 2553-2561. https://doi.org/10.2147/rmhp.s277375

Abdulqadhr, G., Molin, D., Åström, G., Suurküla, M., Johansson, L., Hagberg, H., … & Åhlström, H. (2011). Whole-body diffusion-weighted imaging compared with fdg-pet/ct in staging of lymphoma patients. Acta Radiologica, 52(2), 173-180. https://doi.org/10.1258/ar.2010.100246

Adams, H. and Kwee, T. (2016). Proportion of false-positive lesions at interim and end-of-treatment fdg-pet in lymphoma as determined by histology: systematic review and meta-analysis. European Journal of Radiology, 85(11), 1963-1970. https://doi.org/10.1016/j.ejrad.2016.08.011

Agrawal, A. and Rangarajan, V. (2015). Appropriateness criteria of fdg pet/ct in oncology. Indian Journal of Radiology and Imaging, 25(02), 88-101. https://doi.org/10.4103/0971-3026.155823

Ahmed, A., Sheikh, R., & Ali, M. (2020). Pet/ct vs cect in assessment of therapeutic response in lymphoma. Egyptian Journal of Radiology and Nuclear Medicine, 51(1). https://doi.org/10.1186/s43055-020-00353-5

Albano, D., Borghesi, A., Bosio, G., Bertoli, M., Maroldi, R., Giubbini, R., … & Bertagna, F. (2017). Pulmonary mucosa-associated lymphoid tissue lymphoma: 18f-fdg pet/ct and ct findings in 28 patients. British Journal of Radiology, 90(1079). https://doi.org/10.1259/bjr.20170311

Albano, D., Bruno, A., Patti, C., Micci, G., Midiri, M., Tarella, C., … & Galia, M. (2019). Whole-body magnetic resonance imaging (wb-mri) in lymphoma: state of the art. Hematological Oncology, 38(1), 12-21. https://doi.org/10.1002/hon.2676

Al-Dawsari, N. and Amra, N. (2016). Pattern of skin cancer among saudi patients attending a tertiary care center in dhahran, eastern province of saudi arabia. a 20-year retrospective study. International Journal of Dermatology, 55(12), 1396-1401. https://doi.org/10.1111/ijd.13320

Alfaqeeh, G., Cook, E., Randhawa, G., & Ali, N. (2017). Access and utilisation of primary health care services comparing urban and rural areas of riyadh providence, kingdom of saudi arabia. BMC Health Services Research, 17(1). https://doi.org/10.1186/s12913-017-1983-z

Alhowail, A. (2024). Evaluation of the critical thinking skills of secondary school students in saudi arabia. Problems of Education in the 21st Century, 82(1), 7-28. https://doi.org/10.33225/pec/24.82.07

Alinari, L., Castellucci, P., Elstrom, R., Ambrosini, V., Stefoni, V., Nanni, C., … & Zinzani, P. (2006). 18f-fdg pet in mucosa-associated lymphoid tissue (malt) lymphoma. Leukemia & Lymphoma, 47(10), 2096-2101. https://doi.org/10.1080/10428190600733499

Alkhudair, N., Alshamrani, M., Samarkandi, H., Almodaheem, H., Alabdulkarim, H., Alsaqa'aby, M., … & Al-Jedai, A. (2021). Cancer management in saudi arabia: recommendations by the saudi oncology health economics expert group (sharp). Saudi Pharmaceutical Journal, 29(2), 115-120. https://doi.org/10.1016/j.jsps.2020.12.005

Al-Mana, N. (2024). Evaluation of the use of telehealth in dietetics' practice during the covid-19 pandemic in the kingdom of saudi arabia. Proceedings of the Nutrition Society, 83(OCE2). https://doi.org/10.1017/s0029665124004324

Almaqhawi, A. (2023). Knowledge and attitudes regarding clinical trial participation: a cross-sectional study in the eastern province, saudi arabia. Cureus. https://doi.org/10.7759/cureus.47823

Almutairi, K., Alonazi, W., Alodhayani, A., Vinluan, J., Moussa, M., Al-Ajlan, A., … & Alotaibi, N. (2016). Barriers to cancer clinical trial participation among saudi nationals: a cross-sectional study. Journal of Religion and Health, 56(2), 623-634. https://doi.org/10.1007/s10943-016-0306-8

Al-Qahtani, S. (2023). The establishment of national diagnostic reference levels for adult spect-ct in saudi arabia. Journal of Radiological Protection, 43(3), 031505. https://doi.org/10.1088/1361-6498/ace452

Al-Qahtani, W., Almufareh, N., Domiaty, D., Albasher, G., Alduwish, M., Al-Khalaf, H., … & Almutlaq, B. (2020). Epidemiology of cancer in saudi arabia thru 2010–2019: a systematic review with constrained meta-analysis running title: epidemiology of cancer in saudi arabia thru 2010–2019. Aims Public Health, 7(3), 679-696. https://doi.org/10.3934/publichealth.2020053

Al-Rawashdeh, N., Damsees, R., Al-Jeraisy, M., Qasim, E., & Deeb, A. (2019). Knowledge of and attitudes toward clinical trials in saudi arabia: a cross-sectional study. BMJ Open, 9(10), e031305. https://doi.org/10.1136/bmjopen-2019-031305

Al-Sanea, N., Abduljabbar, A., Alhomoud, S., Ashari, L., Hibbert, D., & Bazarbashi, S. (2015). Colorectal cancer in saudi arabia: incidence, survival, demographics and implications for national policies. Annals of Saudi Medicine, 35(3), 196-202. https://doi.org/10.5144/0256-4947.2015.196

Alshagrawi, S. (2023). Factors associated with access to the saudi primary healthcare in light of vision 2030. Sudan Journal of Medical Sciences. https://doi.org/10.18502/sjms.v18i3.14092

Alshammary, S., Duraisamy, B., Salem, L., & Altamimi, A. (2020). Integration of palliative care into primary health care: model of care experience. Cureus. https://doi.org/10.7759/cureus.8866

AlSheef, M., Bazarbashi, S., Warsi, A., Alfraih, F., Almoomen, A., Osman, A., … & Owaidah, T. (2023). The saudi consensus for the management of cancer-associated thromboembolism: a modified delphi-based study. Th Open, 07(01), e14-e29. https://doi.org/10.1055/s-0042-1758856

Alsuhebany, N. (2024). Ambulatory care hematology/oncology pharmacy services: a comprehensive review by the saudi oncology pharmacy assembly. Journal of the American College of Clinical Pharmacy, 7(6), 570-580. https://doi.org/10.1002/jac5.1960

Al-Tannir, M., El-Bakri, N., & Shaheen, A. (2016). Knowledge, attitudes and perceptions of saudis towards participating in clinical trials. Plos One, 11(2), e0143893. https://doi.org/10.1371/journal.pone.0143893

Althubiti, M. and Eldein, M. (2018). Trends in the incidence and mortality of cancer in saudi arabia. Saudi Medical Journal, 39(12), 1259-1262. https://doi.org/10.15537/smj.2018.12.23348

Alzahrani, M., Altowairqi, M., Alyousef, M., Ghandour, M., Alrashed, A., Aljebrin, Y., … & Alotheem, G. (2022). Survival and epidemiologic trends of lymphomas in saudi arabia: a 10-year report from a tertiary care hospital. Saudi Journal of Medicine and Medical Sciences,

10(1), 31. https://doi.org/10.4103/sjmms.sjmms_200_21

Arts, L., Poll-Franse, L., Berg, S., Prins, J., Husson, O., Mols, F., … & Oerlemans, S. (2017). Lymphoma intervention (live) – patient-reported outcome feedback and a web-based self-management intervention for patients with lymphoma: study protocol for a randomised controlled trial. Trials, 18(1). https://doi.org/10.1186/s13063-017-1943-2

Banaser, M., Al-Soqair, N., & Al-Feher, S. (2021). Nurses perception of advance nurse practitioners roles in public hospitals: a qualitative study. Open Journal of Nursing, 11(06), 513-527. https://doi.org/10.4236/ojn.2021.116044

Bawazir, A., Al-Zamel, N., Amen, A., Akiel, M., Alhawiti, N., & Alshehri, A. (2019). The burden of leukemia in the kingdom of saudi arabia: 15 years period (1999–2013). BMC Cancer, 19(1). https://doi.org/10.1186/s12885-019-5897-5

Beyer, T., Czernin, J., & Freudenberg, L. (2011). Variations in clinical pet/ct operations: results of an international survey of active pet/ct users. Journal of Nuclear Medicine, 52(2), 303-310. https://doi.org/10.2967/jnumed.110.079624

Bodet-Milin, C., Eugène, T., Gastinne, T., Frampas, É., Gouill, S., & Kraeber-Bodéré, F. (2012). Fdg-pet in follicular lymphoma management. Journal of Oncology, 2012, 1-8. https://doi.org/10.1155/2012/370272

Buck, A., Bommer, M., Stilgenbauer, S., Juweid, M., Glatting, G., Schirrmeister, H., … & Reske, S. (2006). Molecular imaging of proliferation in malignant lymphoma. Cancer Research, 66(22), 11055-11061. https://doi.org/10.1158/0008-5472.can-06-1955

Cadavid, L., Sastoque, J., Gutiérrez, C., Yabur, M., & Molina, G. (2017). Primary osseous burkitt lymphoma with nodal and intracardiac metastases in a child. Radiology Case Reports, 12(1), 185-190. https://doi.org/10.1016/j.radcr.2016.11.020

Chen, J., Yan, X., Sheng, Z., & Sun, C. (2022). Demand experience of lymphoma patients with full disease trajectory : a qualitative research. https://doi.org/10.21203/rs.3.rs-1730282/v1

Cunha, G., Alçada, M., Mestre, A., Duarte, M., & Roque, F. (2022). Primary bone lymphoma: a rare cause of chronic back pain. Cureus. https://doi.org/10.7759/cureus.21147

Das, D., Sheikh, Z., Al-Shama'a, M., John, B., Alawi, A., & Junaid, T. (2016). A case of composite classical and nodular lymphocyte predominant hodgkin lymphoma with progression to diffuse large b-cell non-hodgkin lymphoma: diagnostic difficulty in fine-needle aspiration cytology. Diagnostic Cytopathology, 45(3), 262-266. https://doi.org/10.1002/dc.23643

Deja, A. (2023). Esophageal cancer — the utility of pet/ct in staging prior to chemoradiation. Reports of Practical Oncology & Radiotherapy. https://doi.org/10.5603/rpor.96869

Ding, W., Zhao, S., Wang, J., Yang, Q., Sun, H., Yan, J., … & Liu, W. (2015). Gastrointestinal lymphoma in southwest china: subtype distribution of 1,010 cases using the who (2008) classification in a single institution. Acta Haematologica, 135(1), 21-28. https://doi.org/10.1159/000437130

Eich, H. (2023). Evolution of radiation fields from involved field to involved site—a summary of the current guidelines by the international lymphoma radiation oncology group. Lymphatics, 1(3), 262-272. https://doi.org/10.3390/lymphatics1030017

Elasbali, A., Alharbi, H., Alonzi, Z., Hamza, A., Khalafalla, E., & Ahmed, H. (2018). Epidemiology and patterns of malignant lymphoma in northern saudi arabia. Open Journal of Blood Diseases, 08(04), 83-89. https://doi.org/10.4236/ojbd.2018.84009

El-Galaly, T., Pedersen, M., Hutchings, M., Mylam, K., Madsen, J., Gang, A., … & Gormsen, L. (2015). Utility of interim and end-of-treatment pet/ct in peripheral t-cell lymphomas: a review of 124 patients. American Journal of Hematology, 90(11), 975-980. https://doi.org/10.1002/ajh.24128

El-Galaly, T., Villa, D., Gormsen, L., Bæch, J., Lo, A., & Cheah, C. (2018). fdg-pet/ct in the management of lymphomas: current status and future directions. Journal of Internal Medicine, 284(4), 358-376. https://doi.org/10.1111/joim.12813

El-Haddad, M., Omar, W., & Mahdy, S. (2015). Role of 18f-fdg pet versus ct scan in evaluation of extra-nodal lymphoma. Journal of Nuclear Medicine & Radiation Therapy, s7. https://doi.org/10.4172/2155-9619.s7-002

El-Mallawany, N., Mutai, M., Mtete, I., Gopal, S., Stanley, C., Wasswa, P., … & Kazembe, P.

(2017). Beyond endemic burkitt lymphoma: navigating challenges of differentiating childhood lymphoma diagnoses amid limitations in pathology resources in lilongwe, malawi. Global Pediatric Health, 4. https://doi.org/10.1177/2333794x17715831

Elourimi, G., Soussan, M., Groh, M., Martin, A., Héran, F., Galatoire, O., … & Abad, S. (2021). F-18 fluorodeoxyglucose pet/ct as a diagnostic tool in orbital inflammatory disorders. Ocular Immunology and Inflammation, 30(7-8), 1803-1809. https://doi.org/10.1080/09273948.2021.1957943

Farghaly, H., Nasr, H., AA, Q., & Elhussein, W. (2015). 18f-fdg pet/ct for first follow-up post chemotherapy in lymphoma: is it mandatory to do whole body scan?. Journal of Cancer Research & Therapy, 3(3), 20-25. https://doi.org/10.14312/2052-4994.2015-4

Fujiwara, H., Maeda, Y., Nawa, Y., Yamakura, M., Ennishi, D., Miyazaki, Y., … & Tanimoto, M. (2011). The utility of positron emission tomography/computed tomography in the staging of extranodal natural killer/t-cell lymphoma. European Journal of Haematology, 87(2), 123-129. https://doi.org/10.1111/j.1600-0609.2011.01645.x

Garza-Morales, R., Ganguly, A., Hernandez, D., & Cantazaro, B. (2023). Primary pancreatic mature t-cell lymphoma as a cause of obstructive jaundice: a case report and review of the literature. Cureus. https://doi.org/10.7759/cureus.40272

Geiger, K., Pasvolsky, O., Berger, T., Raanani, P., Shochat, T., Gurion, R., … & Bernstine, H. (2022). Effect of steroid treatment on the diagnostic yield of baseline 18f-fluorodeoxyglucose positron emission tomography in aggressive b cell lymphoma. Ejnmmi Research, 12(1). https://doi.org/10.1186/s13550-022-00924-9

Ghazwani, E. (2022). Prevalence and determinants of burnout among palliative care clinicians in saudi arabia. Frontiers in Public Health, 9. https://doi.org/10.3389/fpubh.2021.834407

Grueneisen, J., Sawicki, L., Schaarschmidt, B., Suntharalingam, S., Ropp, S., Wetter, A., … & Umutlu, L. (2016). Evaluation of a fast protocol for staging lymphoma patients with integrated pet/mri. Plos One, 11(6), e0157880. https://doi.org/10.1371/journal.pone.0157880

Hatem, J. and Bogusz, A. (2016). An unusual case of extranodal diffuse large b-cell lymphoma infiltrating skeletal muscle: a case report and review of the literature. Case Reports in Pathology, 2016, 1-8. https://doi.org/10.1155/2016/9104839

Iftikhar, A., Magh, A., Cheema, M., Thappa, S., Sahni, S., & Karbowitz, S. (2017). Primary pulmonary malt lymphoma presenting as non-resolving pneumonia. Advances in Respiratory Medicine, 85(4), 202-205. https://doi.org/10.5603/arm.2017.0033

Jamal, B. (2023). Oral cancer staging and clinicopathologic features presenting to oral & maxillofacial surgery practice in saudi arabia. Clinical Cancer Investigation Journal, 12(1), 32-35. https://doi.org/10.51847/gdcamtoqll

Jung, S., Ahn, J., Kim, Y., Kweon, S., Min, J., Bom, H., … & Yang, D. (2015). Prognostic significance of interim pet/ct based on visual, suv-based, and mtv-based assessment in the treatment of peripheral t-cell lymphoma. BMC Cancer, 15(1). https://doi.org/10.1186/s12885-015-1193-1

Juweid, M., Mueller, M., Alhouri, A., A-Risheq, M., & Mottaghy, F. (2021). Positron emission tomography/computed tomography in the management of hodgkin and b-cell non-hodgkin lymphoma: an update. Cancer, 127(20), 3727-3741. https://doi.org/10.1002/cncr.33772

Karam, M., Novak, L., Cyriac, J., Ali, A., Nazeer, T., & Nugent, F. (2006). Role of fluorine-18 fluoro-deoxyglucose positron emission tomography scan in the evaluation and follow-up of patients with low-grade lymphomas. Cancer, 107(1), 175-183. https://doi.org/10.1002/cncr.21967

Karantanis, D., Kalkanis, D., Allen-Auerbach, M., Bogsrud, T., Subramaniam, R., Danielson, A., … & Czernin, J. (2012). Oncologic 18f-fdg pet/ct: referring physicians' point of view. Journal of Nuclear Medicine, 53(10), 1499-1505. https://doi.org/10.2967/jnumed.111.102228

Katsura, M., Nishina, H., Shigemori, Y., & Nakanishi, T. (2015). Extranodal lymphoma originating in the gluteal muscle with adjacent bone involvement and mimicking a soft tissue sarcoma. International Journal of Surgery Case Reports, 7, 161-164. https://doi.org/10.1016/j.ijscr.2015.01.024

Kiamanesh, Z., Ayati, N., Sadeghi, R., Hawkes, E., Lee, S., & Scott, A. (2022). The value of fdg pet/ct imaging in outcome prediction and response assessment of lymphoma patients treated with immunotherapy: a meta-analysis and systematic review. European Journal of Nuclear Medicine and Molecular Imaging, 49(13), 4661-4676. https://doi.org/10.1007/s00259-022-05918-2

Kmira, Z. (2023). A challenging diagnosis of plasmablastic lymphoma: importance of integrating morpholgy immunohistochemistry and flowcytometry findings (case report). Pan African Medical Journal, 45. https://doi.org/10.11604/pamj.2023.45.158.39896

Lahoud, O., Sauter, C., Hamlin, P., & Dahi, P. (2015). High-dose chemotherapy and autologous stem cell transplant in older patients with lymphoma. Current Oncology Reports, 17(9). https://doi.org/10.1007/s11912-015-0465-x

Lee, C., Lim, I., Woo, S., Kim, W., Kim, K., Lee, K., … & Lim, S. (2021). Targeted alpha immunotherapy of cd20-positive b-cell lymphoma model: dosimetry estimate of 225ac-dota-rituximab using 64cu-dota-rituximab. Annals of Nuclear Medicine, 35(5), 639-647. https://doi.org/10.1007/s12149-021-01607-6

Li, X., Fu, Q., Dong, Y., Liu, J., Song, X., Dong, D., … & Xu, W. (2016). 18f-fluorodeoxyglucose positron emission tomography/computed tomography comparison of gastric lymphoma and gastric carcinoma. World Journal of Gastroenterology, 22(34), 7787. https://doi.org/10.3748/wjg.v22.i34.7787

Li, Y., Li, Z., Xia, X., Huang, H., Xia, Z., Lin, T., … & Jiang, W. (2013). Prognostic value of interim and posttherapy 18f-fdg pet/ct in patients with mature t-cell and natural killer cell lymphomas. Journal of Nuclear Medicine, 54(4), 507-515. https://doi.org/10.2967/jnumed.112.110262

London, J., Grados, A., Fermé, C., Charmillon, A., Maurier, F., Deau, B., … & Terrier, B. (2014). Sarcoidosis occurring after lymphoma. Medicine, 93(21), e121. https://doi.org/10.1097/md.0000000000000121

Maccioni, F., Calabrese, A., Manganaro, L., Felice, C., Cardaccio, S., Lopez, M., … & Pulsoni, A. (2021). Mri versus ct and pet/ct in the preoperative assessment of hodgkin and non-hodgkin lymphomas. Hemato, 2(4), 635-644. https://doi.org/10.3390/hemato2040041

Mandava, A., Koppula, V., Wortsman, X., Catalano, O., & Alfageme, F. (2019). The clinical value of imaging in primary cutaneous lymphomas: role of high resolution ultrasound and pet-ct. British Journal of Radiology, 92(1096). https://doi.org/10.1259/bjr.20180904

Mansour, N. (2010). The comparative analysis of pet/ct and contrast ct in the evaluation of patients with lymphoma. The Egyptian Journal Nuclear Medicine, 3(3), 8-17. https://doi.org/10.21608/egyjnm.2010.5496

Mayerhoefer, M., Karanikas, G., Kletter, K., Prosch, H., Kiesewetter, B., Skrabs, C., … & Raderer, M. (2014). Evaluation of diffusion-weighted mri for pretherapeutic assessment and staging of lymphoma: results of a prospective study in 140 patients. Clinical Cancer Research, 20(11), 2984-2993. https://doi.org/10.1158/1078-0432.ccr-13-3355

Metser, U., Dudebout, J., Baetz, T., Hodgson, D., Langer, D., MacCrostie, P., … & Tau, N. (2017). [18f]-fdg pet/ct in the staging and management of indolent lymphoma: a prospective multicenter pet registry study. Cancer, 123(15), 2860-2866. https://doi.org/10.1002/cncr.30672

Mezger, N., Hämmerl, L., Griesel, M., Seraphin, T., Joko-Fru, Y., Feuchtner, J., … & Kantelhardt, E. (2023). Guideline concordance of treatment and outcomes among adult non-hodgkin lymphoma patients in sub-saharan africa: a multinational, population-based cohort. The Oncologist, 28(11), e1017-e1030. https://doi.org/10.1093/oncolo/oyad157

Minamimoto, R., Tateishi, U., Tomita, N., Inayama, Y., Omura-Minamisawa, M., Tayama, Y., … & Inoue, T. (2010). F-18 fdg pet/ct evaluation of radiotherapy response in rare case of mucosa-associated lymphoid tissue lymphoma. Annals of Nuclear Medicine, 24(2), 115-119. https://doi.org/10.1007/s12149-009-0335-4

Moon, S., Cho, S., Kim, W., Kim, S., Ahn, Y., Choe, Y., … & Choi, J. (2013). The role of18f-fdg pet/ct for initial staging of nasal type natural killer/t-cell lymphoma: a comparison with conventional staging methods. Journal of Nuclear Medicine, 54(7), 1039-1044. https://doi.org/10.2967/jnumed.112.113399

Mutlu, Y., Aydın, B., Çakır, A., Canöz, Ö., Erol, C., & Sevindik, O. (2023). Should core needle lymph node biopsy be a relevant alternative to surgical excisional biopsy in diagnostic work up of lymphomas?. Eurasian J Med, 55(2), 114-119. https://doi.org/10.5152/eurasianjmed.2023.0060

Okuyucu, K., Ince, S., Alagoz, E., Ataş, E., & Arslan, N. (2018). Utility of fdg pet/ct in the management of primary testicular lymphoma. Molecular Imaging and Radionuclide Therapy,

27(2), 61-65. https://doi.org/10.4274/mirt.14227

Ömür, Ö., Baran, Y., Oral, A., & Ceylan, Y. (2014). Fluorine-18 fluorodeoxyglucose pet-ct for extranodal staging of non-hodgkin and hodgkin lymphoma. Diagnostic and Interventional Radiology. https://doi.org/10.5152/dir.2013.13174

Ora, M., Singh, V., Mishra, A., Kalimuthu, L., Nazar, A., & Gambhir, S. (2022). Utility of f-18 fluorodeoxyglucose positron emission tomography - computed tomography in primary thyroid lymphoma. Indian Journal of Nuclear Medicine, 37(4), 379. https://doi.org/10.4103/ijnm.ijnm_72_22.

Otaybi, H., Al-Raddadi, R., & Bakhamees, F. (2022). Performance, barriers, and satisfaction of healthcare workers toward electronic medical records in saudi arabia: a national multicenter study. Cureus. https://doi.org/10.7759/cureus.21899

Othman, A., Nasr, M., & Abdelkawi, M. (2019). Beyond lymph nodes: 18f-fdg pet/ct in detection of unusual sites of extranodal lymphoma. Egyptian Journal of Radiology and Nuclear Medicine, 50(1). https://doi.org/10.1186/s43055-019-0011-1

Pan, Q., Luo, Y., Zhang, Y., Chang, L., Li, J., Cao, X., … & Li, F. (2020). Preliminary evidence of imaging of chemokine receptor-4-targeted pet/ct with [68ga]pentixafor in non-hodgkin lymphoma: comparison to [18f]fdg. Ejnmmi Research, 10(1). https://doi.org/10.1186/s13550-020-00681-7

Pantiora, E., Kontis, E., Michalaki, V., Primetis, E., Vezakis, A., Polydorou, A., … & Fragulidis, G. (2016). Granuloma mimicking local recurrence on pet/ct after liver resection of colorectal liver metastasis: a case report. Cureus. https://doi.org/10.7759/cureus.717

Park, J., Kim, S., Ryu, J., Lee, S., Park, C., Huh, J., … & Suh, C. (2017). Complete metabolic response (cmr) in positron emission tomography–computed tomography (pet-ct) scans may have prognostic significance in patients with marginal zone lymphomas (mzl). Hematological Oncology, 36(1), 56-61. https://doi.org/10.1002/hon.2414

Patel, A., Gujar, S., Pohekar, S., Ankar, R., Raut, A., Sakharkar, S., … & Wagh, P. (2021). Non-hodgkin's lymphoma: a case report. Journal of Pharmaceutical Research International, 264-267. https://doi.org/10.9734/jpri/2021/v33i53b33705

Perry, C., Herishanu, Y., Metzer, U., Bairey, O., Ruchlemer, R., Trejo, L., … & Polliack, A. (2007). Diagnostic accuracy of pet/ct in patients with extranodal marginal zone malt lymphoma. European Journal of Haematology, 79(3), 205-209. https://doi.org/10.1111/j.1600-0609.2007.00895.x

Picardi, M., Cavaliere, C., Pepa, R., Nicolai, E., Soricelli, A., Giordano, C., … & Pane, F. (2021). Pet/mri for staging patients with hodgkin lymphoma: equivalent results with pet/ct in a prospective trial. Annals of Hematology, 100(6), 1525-1535. https://doi.org/10.1007/s00277-021-04537-5

Piciu, D., Meşter, A., Căinap, C., Bărbuş, E., & Morariu, D. (2020). Left supraclavicular lymph node metastasis from ovarian cancer associated with papillary thyroid microcarcinoma, a confusing pathology-essential role of functional imaging. Diagnostics, 10(5), 270. https://doi.org/10.3390/diagnostics10050270

Qiu, L., Lan, L., Liu, H., Wang, Y., Deng, J., Peng, D., … & Chen, Y. (2021). The potential utility of 68ga-fapi-04 as a novel broad-spectrum tumor and inflammatory imaging agent - comparison with 18f-fdg. https://doi.org/10.21203/rs.3.rs-600486/v1

Ravichandran, K., Al-Hamdan, N., & Mohamed, G. (2011). Knowledge, attitude, and behavior among saudis toward cancer preventive practice. Journal of Family and Community Medicine, 18(3), 135. https://doi.org/10.4103/2230-8229.90013

Regacini, R., Puchnick, A., Shigueoka, D., Iared, W., & Lederman, H. (2015). Whole-body diffusion-weighted magnetic resonance imaging versus fdg-pet/ct for initial lymphoma staging: systematic review on diagnostic test accuracy studies. Sao Paulo Medical Journal, 133(2), 141-150. https://doi.org/10.1590/1516-3180.2014.8312810

Sato, K., Ozaki, K., Fujiwara, S., Oh, I., Matsuyama, T., Ohmine, K., … & Ozawa, K. (2010). Incidental carcinomas detected by pet/ct scans in patients with malignant lymphoma. International Journal of Hematology, 92(4), 647-650. https://doi.org/10.1007/s12185-010-0702-x

Sato, M., Sakon, K., Tanaka, K., Mizunaga, T., Yano, K., Kawamura, Y., … & Koshiji, T. (2021). Case of a lung collision tumor consisting of squamous cell carcinoma of the lung and diffuse large b-cell lymphoma.. https://doi.org/10.21203/rs.3.rs-146992/v1

Stecco, A., Buemi, F., Quagliozzi, M., Lombardi, M., Santagostino, A., Sacchetti, G., … & Carriero, A. (2015). Staging of primary abdominal lymphomas: comparison of whole-body

mri with diffusion-weighted imaging and18f-fdg-pet/ct. Gastroenterology Research and Practice, 2015, 1-8. https://doi.org/10.1155/2015/104794

Teimoorisichani, M., Mingels, C., Alberts, I., Panin, V., Bharkhada, D., Xue, S., … & Rominger, A. (2022). Quantitative evaluation of a deep learning-based framework to generate whole-body attenuation maps using lso background radiation in long axial fov pet scanners. European Journal of Nuclear Medicine, 49(13), 4490-4502. https://doi.org/10.1007/s00259-022-05909-3

Thomas, A., Schwartz, M., & Quigley, E. (2019). Gastrointestinal lymphoma: the new mimic. BMJ Open Gastroenterology, 6(1), e000320. https://doi.org/10.1136/bmjgast-2019-000320

Togo, B., Traoré, F., Togo, A., Traoré, C., Dumke, K., Diawara, M., … & Sidibé, T. (2011). Hodgkin lymphoma at the paediatric oncology unit of gabriel touré teaching hospital, bamako, mali: 5-year experience. Advances in Hematology, 2011, 1-6. https://doi.org/10.1155/2011/327237

Tyrovolas, S., Bcheraoui, C., Alghnam, S., Alhabib, K., Almadi, M., Al-Raddadi, R., … & Mokdad, A. (2020). The burden of disease in saudi arabia 1990–2017: results from the global burden of disease study 2017. The Lancet Planetary Health, 4(5), e195-e208. https://doi.org/10.1016/s2542-5196(20)30075-9

Valli, V., Myint, M., Barthel, A., Bienzle, D., Caswell, J., Colbatzky, F., … & Vernau, W. (2010). Classification of canine malignant lymphomas according to the world health organization criteria. Veterinary Pathology, 48(1), 198-211. https://doi.org/10.1177/0300985810379428

Vassilakopoulos, T., Prassopoulos, V., Rondogianni, P., Chatziioannou, S., Konstantopoulos, K., & Angelopoulou, M. (2015). Role of fdg-pet/ct in staging and first-line treatment of hodgkin and aggressive b-cell lymphomas. Memo - Magazine of European Medical Oncology, 8(2), 105-114. https://doi.org/10.1007/s12254-015-0215-7

Wang, D., Huo, Y., Chen, S., Wang, H., Ding, Y., & Zhu, X. (2018). Whole-body mri versus ¹⁸f-fdg pet/ct for pretherapeutic assessment and staging of lymphoma: a meta-analysis. Oncotargets and Therapy, Volume 11, 3597-3608. https://doi.org/10.2147/ott.s148189

Waqar, S., Siddiqui, T., Sadiq, H., Sarfraz, M., Sarfraz, K., & Mannan, M. (2023). Diagnostic accuracy of pet/ct in detecting aggressiveness of lymphoma based on sub uptake. Pakistan Armed Forces Medical Journal, 73(2), 494-97. https://doi.org/10.51253/pafmj.v73i2.7593

Wazqar, D., Kerr, M., Regan, S., & Orchard, C. (2017). Overview of cancer care and oncology nursing in the kingdom of saudi arabia. American Journal of Nursing Science, 6(4), 324. https://doi.org/10.11648/j.ajns.20170604.17

Weber, M., Jentzen, W., Hofferber, R., Herrmann, K., Fendler, W., Rischpler, C., … & Kersting, D. (2021). Evaluation of 18f-fdg pet/ct images acquired with a reduced scan time duration in lymphoma patients using the digital biograph vision. BMC Cancer, 21(1). https://doi.org/10.1186/s12885-020-07723-2

Wei, W., Huang, J., Li, W., Xia, Y., Jiang, W., Fan, W., … & Li, Z. (2015). Prognostic values of interim and post-therapy 18f-fdg pet/ct scanning in adult patients with burkitt's lymphoma. Chinese Journal of Cancer, 34(3). https://doi.org/10.1186/s40880-015-0057-z

Wu, H., Wang, Q., Wang, M., Li, H., Zhou, W., Ye, X., … & Wang, Q. (2010). Utility of 18f-fdg pet/ct for staging nk/t-cell lymphomas. Nuclear Medicine Communications, 31(3), 195-200. https://doi.org/10.1097/mnm.0b013e32833310fa

Yonese, I., Takase, H., Yoshimori, M., Onozawa, E., Tsuzura, A., Miki, T., … & Arai, A. (2018). cd79b mutations in primary vitreoretinal lymphoma: diagnostic and prognostic potential. European Journal of Haematology, 102(2), 191-196. https://doi.org/10.1111/ejh.13191

Yoo, K. (2022). Staging and response assessment of lymphoma: a brief review of the lugano classification and the role of fdg-pet/ct. Blood Research, 57(S1), S75-S78. https://doi.org/10.5045/br.2022.2022055

Zheng, Y. (2024). Survival trend and outcome prediction for pediatric hodgkin and non-hodgkin lymphomas based on machine learning. Clinical and Experimental Medicine, 24(1). https://doi.org/10.1007/s10238-024-01402-3

Zhou, X., Lu, K., Geng, L., Li, X., Jiang, Y., & Wang, X. (2014). Utility of pet/ct in the diagnosis and staging of extranodal natural killer/t-cell lymphoma. Medicine, 93(28), e258. https://doi.org/10.1097/md.0000000000000258

Zou, Y., Tong, J., Leng, H., Jiang, J., Pan, M., & Chen, Z. (2017). Diagnostic value of using 18f-fdg pet and pet/ct in immunocompetent patients with primary central nervous system lymphoma: a systematic review and meta-analysis. Oncotarget, 8(25), 41518-41528. https://doi.org/10.18632/oncotarget.17456

Zytoon, A., Mohamed, H., Mostafa, B., & Houseni, M. (2020). Pet/ct and contrast-enhanced ct: making a difference in assessment and staging of patients with lymphoma. Egyptian Journal of Radiology and Nuclear Medicine, 51(1). https://doi.org/10.1186/s43055-020-00320-0