



شبكة المعلومات الجامعية  
التوثيق الإلكتروني والميكرو فيلم

# بسم الله الرحمن الرحيم



**HANAA ALY**



شبكة المعلومات الجامعية  
التوثيق الإلكتروني والميكروفيلم



# شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



**HANAA ALY**



شبكة المعلومات الجامعية  
التوثيق الإلكتروني والميكروفيلم

# جامعة عين شمس

## التوثيق الإلكتروني والميكروفيلم

### قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها  
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



### يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



**HANAA ALY**



**Role of PET/CT in initial evaluation of lymphoma patients.**

**Protocol of a thesis for partial fulfillment of MD degree in radiology**

Presented by

**Manar Mohamed Naguib Elsaeed**

Assistant Lecturer of radiology.

Faculty of medicine-Ain-shams university

**Supervised by**

**Prof. Dr. Samer Malak Botros**

Professor of Radiology

Radio-diagnosis department-Ain-shams university

**Dr. Amir Louis Louka**

Lecturer of Radiology

Radio-diagnosis Department-Ain-shams university

**Dr. Rasha Salah El-din Hussein**

Lecturer of Radiology

Radio-diagnosis Department-Ain-shams University

Faculty of Medicine

Ain Shams University

2022

# **Contents**

	<b><u>PAGE</u></b> <b><u>No.</u></b>
<b>List of Abbreviations</b>	<b>I</b>
<b>List of Figures</b>	<b>III</b>
<b>List of Tables</b>	<b>VIII</b>
<b>Introduction and aim of the work</b>	<b>1</b>
<b><u>Review of Literature:</u></b>	
• <b>Lymphoma epidemiology.</b>	<b>5</b>
• <b>Background of PET/CT scanner and interpretation.</b>	<b>31</b>
<b>PET-CT in initial evaluation of lymphoma patients.</b>	<b>111</b>
<b>Patients and methods.</b>	<b>152</b>
<b>Results.</b>	<b>156</b>
<b>Illustrative cases.</b>	<b>180</b>
<b>Discussion</b>	<b>192</b>
<b>Conclusion.</b>	<b>200</b>
<b>References.</b>	<b>201</b>
<b>Arabic summary.</b>	

## **List of Abbreviations**

<b>Abbreviation</b>	
<b>PET</b>	Positron emission tomography
<b>ENL</b>	Extra-nodal lymphoma
<b>FDG</b>	Flouro-deoxyglucose
<b>CECT</b>	Contrast enhanced computed tomography
<b>GLUTs</b>	Glucose transporters
<b>PDGF</b>	Platelet derived growth factor
<b>VEGF</b>	Vascular endothelial growth factor
<b>BFGF</b>	Basic fibroblast growth factor
<b>SUV</b>	Standardized uptake value
<b>BAT</b>	Brown adipose tissue
<b>ROIs</b>	Regions of interest
<b>IASLC</b>	International Association for the Study of Lung Cancer
<b>WHO</b>	World Health Organization
<b>DLBCL</b>	Diffuse large B-cell lymphoma
<b>NHL</b>	Non-Hodgkin lymphoma
<b>FL</b>	Follicular lymphoma
<b>MALT</b>	Mucosa associated lymphoid tissue
<b>MCL</b>	Mantle cell lymphoma
<b>HD</b>	Hodgkin Disease
<b>HL</b>	Hodgkin lymphoma
<b>TNM</b>	Tumor Node Metastasis
<b>NK</b>	Natural killer
<b>Mev</b>	Milli electron volt
<b>Kev</b>	Kilo electron volt
<b>HU</b>	Housefield unit
<b>Mci</b>	millicurie
<b>MZL</b>	Marginal zone lymphoma
<b>IFRT</b>	Involved field radiotherapy
<b>μ map</b>	Attenuation map

<b>SUV</b>	Standardized Uptake Value
<b>MTV</b>	Metabolic tumor volume
<b>TLG</b>	Total lesion glycolysis
<b>CMR</b>	complete metabolic response
<b>PMR</b>	partial metabolic response
<b>SMD</b>	stable metabolic disease
<b>PMD</b>	progressive metabolic disease
<b>IQR</b>	interquartile range
<b>PPV</b>	Positive predictive values.
<b>NPV</b>	Negative predictive values.
<b>AUC</b>	Area under curves.
<b>NCCN-IPI</b>	National cancer Network International Prognostic Index



## **List of figure**

<b><u>Figure no.</u></b>	<b><u>CONTENT</u></b>	<b><u>Page</u></b>
<b><u>1</u></b>	The lymphoid regions	<b><u>20</u></b>
<b><u>2</u></b>	Photograph of a hybrid PET-CT scanner.	<b><u>32</u></b>
<b><u>3</u></b>	Illustrative diagram of combined PET/CT scanner components.	<b><u>33</u></b>
<b><u>4</u></b>	Imaging protocol for combined PET/CT.	<b><u>35</u></b>
<b><u>5</u></b>	Annihilation reaction.	<b><u>36</u></b>
<b><u>6</u></b>	Production of F-18.	<b><u>38</u></b>
<b><u>7</u></b>	Uptake of FDG	<b><u>40</u></b>
<b><u>8</u></b>	Structure and metabolism of FDG.	<b><u>41</u></b>
<b><u>9</u></b>	Transmission scans used PET attenuation correction factors.	<b><u>43</u></b>
<b><u>10</u></b>	Linear attenuation co-efficients for bone and muscle.	<b><u>44</u></b>
<b><u>11</u></b>	Misregistration artifact.	<b><u>45</u></b>
<b><u>12</u></b>	Curvilinear cold artifact.	<b><u>46</u></b>
<b><u>13</u></b>	Respiratory motion artifact.	<b><u>46</u></b>
<b><u>14</u></b>	Implantable catheter port artifact	<b><u>48</u></b>
<b><u>15</u></b>	Metallic implants artifact.	<b><u>49</u></b>
<b><u>16</u></b>	Intravenous contrast material artifact.	<b><u>50</u></b>
<b><u>17</u></b>	Oral contrast material artifact.	<b><u>50</u></b>
<b><u>18</u></b>	Effect of exercise on skeletal muscle 18F-FDG uptake.	<b><u>53</u></b>
<b><u>19</u></b>	Brown fat 18F-FDG uptake.	<b><u>55</u></b>
<b><u>20</u></b>	Imaging protocol for PET/CT.	<b><u>59</u></b>
<b><u>21</u></b>	Physiologic FDG uptake in the thymus.	<b><u>64</u></b>
<b><u>22</u></b>	Physiologic submandibular uptake.	<b><u>68</u></b>
<b><u>23</u></b>	Normal distribution of FDG.	<b><u>71</u></b>
<b><u>24</u></b>	FDG-uptake in breast.	<b><u>72</u></b>
<b><u>25</u></b>	Post surgical inflammatory FDG uptake.	<b><u>74</u></b>
<b><u>26</u></b>	FDG-avid cavitary granulomatous lesion.	<b><u>75</u></b>
<b><u>27</u></b>	Talc pleurodesis FDG uptake.	<b><u>77</u></b>



<b><u>28</u></b>	Drawing shows anatomy& margins of neck nodal classification.	<b>86</b>
<b><u>29</u></b>	Level I &II nodes of the neck.	<b>87</b>
<b><u>30</u></b>	Level VII nodes of the neck.	<b>88</b>
<b><u>31</u></b>	Level III& Va nodes of the neck.	<b>89</b>
<b><u>32</u></b>	Level IV, Vb& VI nodes of the neck.	<b>90</b>
<b><u>33</u></b>	Illustration shows the IASLC lymph node map.	<b>92</b>
<b><u>34</u></b>	Classification of non-regional thoracic lymph nodes.	<b>95</b>
<b><u>35</u></b>	Method for distinguishing low cervical lymph nodes from superior mediastinal lymph nodes.	<b>96</b>
<b><u>36</u></b>	Stations 3aand 3p of the thoracic lymph nodes.	<b>97</b>
<b><u>37</u></b>	Upper zone: stations 2R, 2L, 3a, 3p, 4R, and 4L of the thoracic lymph nodes.	<b>97</b>
<b><u>38</u></b>	Stations 5 and 6 of the thoracic lymph nodes.	<b>98</b>
<b><u>39</u></b>	Station 7 of thoracic lymph nodes.	<b>99</b>
<b><u>40</u></b>	Lower zone: stations 8 and 9 of thoracic lymph nodes.	<b>100</b>
<b><u>41</u></b>	Stations 10R and 10L of thoracic lymph nodes.	<b>100</b>
<b><u>42</u></b>	Stations 11R and 11L of thoracic lymph nodes.	<b>101</b>
<b><u>43</u></b>	Gastro-oesophageal, hepatic artery, splenic, gastro-omental, left gastric, hepatoduodenal ligament lymph nodes.	<b>104</b>
<b><u>44</u></b>	Left gastric, coeliac, diaphragmatic, paraoesophageal, lesser curvature lymph nodes.	<b>105</b>
<b><u>45</u></b>	Coeliac, hepatic artery, left gastric, gastroduodenal, superior mesenteric lymph nodes.	<b>105</b>
<b><u>46</u></b>	Right colic, superior mesenteric, middle colic, paracolic, left colic, sigmoid, inferior mesenteric lymph nodes.	<b>105</b>
<b><u>47</u></b>	Inter-aortocaval, inguinal, internal iliac, external iliac, pre-caval, common iliac, left para-aortic lymph nodes.	<b>106</b>
<b><u>48</u></b>	Left gastric, greater curvature, left inferior phrenic lymph nodes.	<b>106</b>

<b><u>49</u></b>	Lesser curvature, hepatic artery, greater curvature, pericolic, middle colic lymph nodes.	<b>106</b>
<b><u>50</u></b>	Greater curvature, right gastric, right colic lymph nodes.	<b>107</b>
<b><u>51</u></b>	Gastro-duodenal, pericolic, superior mesenteric, inter aorto-caval, right gastro-epiploic lymph nodes.	<b>107</b>
<b><u>52</u></b>	Right gastroepiploic, peri-portal, superior mesenteric, inferior pancreatic lymph nodes.	<b>107</b>
<b><u>53</u></b>	Splenic, periportal, anterior pancreatic, hepatic lymph nodes.	<b>107</b>
<b><u>54</u></b>	Coeliac axis, hepato-duodenal, common hepatic lymph nodes.	<b>107</b>
<b><u>55</u></b>	Lateral aortic, right gastroepiploic, inter-aortocaval, pyloric, superior mesenteric lymph nodes.	<b>108</b>
<b><u>56</u></b>	Coeliac axis, splenic, greater-omental, anterior pancreatoco-duodenal, posterior pancreatoco-duodenal, inferior pancreatic lymph nodes.	<b>108</b>
<b><u>57</u></b>	Renal hilar, retro-aortic, superior mesenteric lymph nodes.	<b>108</b>
<b><u>58</u></b>	Lateral aortic, retro-caval, inter-aortocaval, juxta-intestinal, pericolic, left colic lymph nodes.	<b>108</b>
<b><u>59</u></b>	Lateral aortic, retro-caval, lateral caval, pre-aortic, pre-caval lymph nodes.	<b>109</b>
<b><u>60</u></b>	Inferior mesenteric, juxta-intestinal, anterior ileo-colic, posterior ileo-colic lymph nodes.	<b>109</b>
<b><u>61</u></b>	Anterior diaphragmatic, gastro-oesophageal, middle diaphragmatic lymph nodes.	<b>109</b>
<b><u>62</u></b>	Retrocrural, inferior diaphragmatic, middle colic lymph nodes.	<b>109</b>
<b><u>63</u></b>	Common iliac lymph nodes.	<b>110</b>
<b><u>64</u></b>	External iliac lymph nodes.	<b>110</b>
<b><u>65</u></b>	Internal iliac lymph nodes.	<b>110</b>
<b><u>66</u></b>	Mantle cell lymphoma.	<b>120</b>
<b><u>67</u></b>	Splenic involvement by NHL.	<b>124</b>
<b><u>68</u></b>	NHL with lymphomatous mass in region of liver.	<b>125</b>

<b><u>69</u></b>	Peritoneal lymphomatosis.	<b>126</b>
<b><u>70</u></b>	Lymphoma involving the gall bladder.	<b>127</b>
<b><u>71</u></b>	Large B-cell lymphoma involving pancreas.	<b>128</b>
<b><u>72</u></b>	Gastric lymphoma.	<b>129</b>
<b><u>73</u></b>	Intestinal lymphoma.	<b>130</b>
<b><u>74</u></b>	Esophageal MALT lymphoma.	<b>131</b>
<b><u>75</u></b>	Head and neck lymphoma with primary diffuse large B-cell carcinoma of the nasopharynx.	<b>133</b>
<b><u>76</u></b>	Primary follicular lymphoma of the parotid and submandibular glands.	<b>134</b>
<b><u>77</u></b>	Lymphoma involving the nervous system.	<b>135</b>
<b><u>78</u></b>	NHL with involvement of the nerve sheet (neuro-lymphomatosis).	<b>136</b>
<b><u>79</u></b>	NHL with lung and mediastinal involvement.	<b>137</b>
<b><u>80</u></b>	Lymphoma involving the pleura.	<b>138</b>
<b><u>81</u></b>	Burkitt's lymphoma involving the breast.	<b>140</b>
<b><u>82</u></b>	Burkitt's lymphoma involving the cervix.	<b>141</b>
<b><u>83</u></b>	NHL involving retroperitoneal nodes, spermatic cord, and testis.	<b>142</b>
<b><u>84</u></b>	Peri-pelvic follicular lymphoma of kidney.	<b>144</b>
<b><u>85</u></b>	Large B-cell lymphoma involving kidneys.	<b>145</b>
<b><u>86</u></b>	NHL involving retro-peritoneal lymph nodes with invasion of left kidney.	<b>145</b>
<b><u>87</u></b>	NHL and extranodal involvement of skeleton and adrenal glands.	<b>146</b>
<b><u>88</u></b>	Primary cutaneous T-cell lymphoma	<b>147</b>
<b><u>89</u></b>	Diffuse reactive bone marrow activity after CTH	<b>148</b>
<b><u>90</u></b>	False-positive impression of diffuse BM involvement after treatment by CTH.	<b>151</b>
<b><u>91</u></b>	Calculation of different PET/CT parameters.	<b>155</b>
<b><u>92</u></b>	Bar chart showing the number of males and females in this study.	<b>157</b>
<b><u>93</u></b>	Bar chart showing the number of patients with Hodgkin and non-Hodgkin lymphomas in this study.	<b>157</b>

<b><u>94</u></b>	Box-and-whisker plots of baseline and post-treatment SUV in both responsive and non-responsive groups.	<b>161</b>
<b><u>95</u></b>	Box-and-whisker plots of baseline and post-treatment MTV in both responsive and non-responsive groups.	<b>162</b>
<b><u>96</u></b>	Box-and-whisker plots of baseline and post-treatment TLG in both responsive and non-responsive groups.	<b>162</b>
<b><u>97</u></b>	Box-and-whisker plots of $\Delta$ SUV max, $\Delta$ MTV, and $\Delta$ TLG in both responsive and non-responsive groups	<b>163</b>
<b><u>98</u></b>	Receiver operating characteristic curve analyses. The specificity and sensitivity of using interim $\Delta$ SUV, $\Delta$ TLG, $\Delta$ MTV, post-treatment MTV, post-treatment TLG and post-treatment SUV in differentiating responsive and non-responsive groups	<b>165</b>
<b><u>99</u></b>	Receiver operating characteristic curve analyses. The specificity and sensitivity of using $\Delta$ SUV, $\Delta$ TLG, $\Delta$ MTV, post-treatment MTV, post-treatment TLG and baseline SUV in differentiating responsive and non-responsive groups	<b>165</b>
<b><u>100</u></b>	Receiver operating characteristic curve analyses. The specificity and sensitivity of using post-treatment and baseline SUV in differentiating responsive and non-responsive groups	<b>166</b>
<b><u>101</u></b>	Box-and-whisker plots of pre-treatment and post-treatment SUV in PMR,CMR, SMD and PMD groups	<b>171</b>
<b><u>102</u></b>	Box-and-whisker plots of pre-treatment and post-treatment MTV in PMR.CMR, SMD and PMD groups.	<b>172</b>
<b><u>103</u></b>	Box-and-whisker plots of pre-treatment and post-treatment TLG in PMR.CMR,SMD and PMD groups	<b>172</b>
<b><u>104</u></b>	Box-and-whisker plots of $\Delta$ SUV max in PMR.CMR, SMD and PMD groups.	<b>173</b>
<b><u>105</u></b>	Box-and-whisker plots of $\Delta$ MTV in PMR.CMR,SMD and PMD groups	<b>174</b>
<b><u>106</u></b>	Box-and-whisker plots of $\Delta$ TLG in PMR.CMR, SMD and PMD groups	<b>174</b>

## **LIST OF TABLES**

<b><u>Table no.</u></b>	<b><u>CONTENT</u></b>	<b><u>Page no.</u></b>
<b><u>1</u></b>	Classification of Non-Hodgkin lymphoma	<b>16</b>
<b><u>2</u></b>	Staging of Non-Hodgkin lymphoma	<b>21</b>
<b><u>3</u></b>	Factors of International Prognostic Index	<b>23</b>
<b><u>4</u></b>	Factors of Follicular Lymphoma International Prognostic Index	<b>24</b>
<b><u>5</u></b>	Diagnostic workup of lymphoma	<b>28</b>
<b><u>6</u></b>	The Lugano classification response criteria	<b>30</b>
<b><u>7</u></b>	Proposed Standard Patient Preparation Protocol for FDG PET and PET-CT.	<b>58</b>
<b><u>8</u></b>	Comparison between the TNM atlas terminology and the Robbins classification of the L.Ns of the neck.	<b>80</b>
<b><u>9</u></b>	Robbins classification for head and neck L.Ns.	<b>81,82</b>
<b><u>10</u></b>	Imaging based nodal classification of the head and neck.	<b>85</b>
<b><u>11</u></b>	Nodal stations and zones in the IASLC lymph node map.	<b>92</b>
<b><u>12</u></b>	Anatomic Definitions and boundaries of the IASLC Lymph Node Stations	<b>93,94</b>
<b><u>13</u></b>	Normal nodal size according to the anatomical regions in abdomen and pelvis.	<b>104</b>
<b><u>14</u></b>	Studies on the Prognostic Value of MTV and TLG in Lymphoma	<b>116-118</b>
<b><u>15</u></b>	FDG uptake in various histologic subtypes of NHL and HL	<b>121</b>
<b><u>16</u></b>	RECIST Criteria	<b>155</b>
<b><u>17</u></b>	Distribution of lesions in the different groups designated according to treatment response	<b>158</b>
<b><u>18</u></b>	Comparison of baseline and post-treatment quantitative PET/CT parameters in both responsive and non-	<b>159</b>

	responsive groups.	
<b><u>19</u></b>	Comparison between quantitative PET/CT parameters of the responsive and non-responsive groups	<b>160-161</b>
<b><u>20</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the responsive group from the non-responsive group.	<b>164</b>
<b><u>21</u></b>	Difference between the ROC curves of all parameters and their statistical significance	<b>166</b>
<b><u>22</u></b>	Comparison of baseline and post – treatment quantitative PET/CT parameters in each group	<b>167</b>
<b><u>23</u></b>	Comparison of quantitative PET/CT parameters between all groups	<b>168-170</b>
<b><u>24</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the CMR group from the PMR group.	<b>175</b>
<b><u>25</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the CMR group from the SMD group.	<b>176</b>
<b><u>26</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the CMR group from the PMD group.	<b>177</b>

<b><u>27</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the PMR group from the SMD group.	<b>178</b>
<b><u>28</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the PMR group from the PMD group.	<b>179</b>
<b><u>29</u></b>	The sensitivities, specificities, positive predictive values (PPV), negative predictive values (NPV), accuracies, area under curves (AUC) and P values of the optimum threshold values of the quantitative PET/CT parameters for differentiation of the PMD group from the SMD group.	<b>179</b>