Clinical Applications of Combined PET/CT in the Head and Neck

Essay

Submitted for fulfillment of the master degree in radiodiagnosis

By

Rania Aly Zeitoun

M.B., B.Ch.

Cairo University

Supervised by

Dr. Amr Osama M. A. Azab

Assistant Professor of Radiodiagnosis

Faculty of Medicine

Cairo University

Dr. Ayman A. Elhameed El-Basmy

Lecturer of Radiodiagnosis

Faculty of Medicine

Cairo University

Faculty of Medicine

Cairo University

2010

Clinical Applications of Combined PET/CT in the Head and Neck

DEDICATION

To the great heroine;

To the infinite love, support and sacrifice;

To the one behind all my achievements and success;

To my great mother;

I dedicate this work and my whole life.

ACKNOWLEDGEMENT

First and foremost, thanks to Allah, the most generous and merciful.

I greatly acknowledge the valuable contribution, generous help and support, guidance and directions of ***Dr. Amr Osama Azab***, Assistant Professor of radiodiagnosis, faculty of Medicine, Cairo University, to accomplish this work.

I also appreciate so much the patience, help and support of **Dr.** ***Ayman A. Elhameed El-Basmy***, Lecturer of radiodiagnosis, faculty of Medicine, Cairo University.

Words are not enough to express my deep gratitude and great thanks to all my family members who provided me their kind love, care and support all through my life. In particular, I would like to express my deepest gratitude to ***my mother and sister*** for their great support while preparing this work.

ABSTRACT

In the last decade, ***Combined PET/CT*** has been introduced into the field of oncologic imaging representing a unique imaging modality that scans the whole body integrating functional information from a PET scan with anatomical information from a CT scan. Combined PET/CT is considered a major breakthrough in oncologic imaging with valuable applications in head and neck malignancies. It is very efficient with least possible pitfalls and false results compared to either of its components alone and to side by side reading of separately acquired PET and CT. It can be a standard modality for lymphoma providing a new vision to management and treatment plan. The future of Combined PET/CT seems bright with new applications are awaited with great interest.

List of Contents

INTRODUCTION 1

AIM OF WORK 2

PET/CT PHYSICS AND INSTRUMENTATION 3

PET/CT RADIOPHARMACEUTICALS 16

PHYSIOLOGIC DISTRIBUTION OF 18F-FDG IN THE BODY AND NORMAL VARIANTS 22

TECHNIQUE OF PET/CT EXAMINATION 38

INTERPRETATION OF PET/CT IMAGES 45

CROSS-SECTIONAL ANATOMY OF THE HEAD AND NECK 54

ONCOLOGICAL APPLICATIONS OF PET/CT 64

PET/CT IN NASOPHARYNGEAL CARCINOMA 67

PET/CT IN ORAL AND ORO-PHARYNGEAL CARCINOMA 78

PET/CT IN LARYNGEAL AND HYPOPHARYNGEAL MALIGNANCIES 84

PET/CT IN SALIVARY GLANDS MALIGNANCIES 93

PET/CT IN THYROID CANCER 105

PET/CT IN CARCINOMA OF UNKNOWN PRIMARY 116

PET/CT IN LYMPHOMA 118

PET/CT IN RADIOTHERAPY PLANNING 135

SUMMARY AND CONCLUSION 141

REFERENCES 148

List of Figures

Figure 1: Positron decay 4
Figure 2: Positron range and annihilation angle blurring 5
Figure 3: Coincidence detection 6
Figure 4: Types of coincident events 7
Figure 5: Two-dimensional and Three-dimensional imaging 8
Figure 6: Attenuation and non attenuation corrected images 9
Figure 7: Image reconstruction 10
Figure 8: Block detector design 13
Figure 9: Field of view 14
Figure 10: Radial blurring 14
Figure 11: Combined PET/CT scanners 15
Figure 12: Production of 18F 17
Figure 13: Schematic structure of FDG 18
Figure 14: Schematic synthesis of FDG 19
Figure 15: Schematic illustration of FDG uptake 20
Figure 16: Physiologic FDG uptake in palatine and lingual tonsils 23
Figure 17: Physiologic FDG uptake in the tonsils 23
Figure 18: Physiologic FDG uptake in parotid and submandibular glands 24
Figure 19: Asymmetric FDG uptake in the left side of nasopharynx 25
Figure 20: Normal pattern of laryngeal uptake 25
Figure 21: Unilateral vocal cord uptake 26
Figure 22: Diffuse and focal uptake in the thyroid gland 27
Figure 23: Physiologic uptake in neck muscles 28
Figure 24: Physiologic uptake in genioglossus muscle 28
Figure 25: Physiologic cardiac uptake 29
Figure 26: Physiologic uptake in thymus gland and glandular breast tissue 30
Figure 27: Uptake in perivascular tumor tissue 31
Figure 28: Splenic uptake 32
Figure 29: Physiologic bowel uptake 33
Figure 30: Physiologic ureteric uptake 34
Figure 31: Diffuse marrow uptake 35
Figure 32: Focal marrow uptake 35

Figure 33: Physiologic muscular uptake 36
Figure 34: Physiologic uptake in brown fat 37
Figure 35: Misregistration artifacts in head and neck 50
Figure 36: Misregistration artifacts in lung/diaphragm interface 51
Figure 37: Attenuation correction artifacts due to oral contrast agents 52
Figure 38: Attenuation correction artifacts due to IV contrast 52
Figure 39: Attenuation correction artifacts due to metallic prothesis 53
Figure 40: Axial Cross-sectional anatomy at the level of the skull base 54
Figure 41: Axial Cross-sectional anatomy at the level of the upper maxillary antrum 56
Figure 42: Axial Cross-sectional anatomy at the level of the lower maxillary antrum 57
Figure 43: Axial Cross-sectional anatomy at the level of the alveolar ridge 59
Figure 44: Axial Cross-sectional anatomy at the level of the mandible 60
Figure 45: Axial Cross-sectional anatomy at the level of the C4 vertebra 61
Figure 46: Axial Cross-sectional anatomy at the level of the C6 vertebra 61
Figure 47: Axial Cross-sectional anatomy at the level of the C7 vertebra 62
Figure 48: Nodal levels in the neck 63
Figure 49: The involvement of parapharyngeal space by NPC (MR vs. PET/CT) 70
Figure 50: A case with NPC showing perineural tumor extension 71
Figure 51: Retropharyngeal lymph node metastases in a case of NPC 72
Figure 52: A case with NPC showing bone metastases 73
Figure 53: A case with NPC showing a metastatic lesion in the periphery of left lobe of liver 74
Figure 54: A case with NPC showing a small metastatic lung nodule 74
Figure 55: Recurrent metastatic NPC 76
Figure 56: Exclusion of recurrent NPC by PET 76
Figure 57: Uptake by post therapeutic inflammatory changes in NPC 77
Figure 58: Inhibited metabolic activity in residual tumor after radiotherapy in NPC 77
Figure 59: Detection of oral SCC by PET 80
Figure 60: Mandibular involvement by PET vs. CT 81
Figure 61: Nodal metastases in oral SCC by PET vs. MRI 82
Figure 62: Detection of synchronous lung lesion in oral SCC by PET/CT 82
Figure 63: Recurrent tongue SCC 83
Figure 64: PET/CT staging in a patient with hypopharyngeal cancer 89
Figure 65: Piriform sinus carcinoma by PET/CT 90

Figure 66: Recurrent laryngeal carcinoma by PET/CT ... 90
Figure 67: Exclusion of recurrent laryngeal carcinoma by PET/CT ... 91
Figure 68: PET/CT guides to biopsy site in post radiotherapy edematous larynx ... 92
Figure 69: Detection of parotid malignancy by PET ... 117
Figure 70: Diagnosis of warthin tumor in parotid gland by PET and Scintigraphy ... 98
Figure 71: Diagnosis of carcinoma in parotid gland by PET vs. Scintigraphy ... 98
Figure 72: Physiologic FDG uptake by the parotid obscuring low grade malignancy ... 99
Figure 73: Carcinoma of the sublingual gland by CT vs. PET/CT ... 99
Figure 74: Recurrent parotid carcinoma by PET ... 101
Figure 75: Recurrent parotid carcinoma at the facial canal by PET/CT ... 102
Figure 76: Detecting scintigraphically occult metastatic thyroid cancer by PET/CT ... 103
Figure 77: Detecting scintigraphically occult metastatic thyroid cancer by PET/CT ... 111
Figure 78: Characterization of thyroid incidentalomas by PET/CT ... 112
Figure 79: Characterization of thyroid incidentalomas by PET/CT ... 114
Figure 80: PET/CT guides biopsy site in CUP ... 115
Figure 81: Detection of lymphoma in a small node by PET/CT ... 122
Figure 82: Staging of NHL by PET/CT ... 123
Figure 83: Detection of nodal and extra nodal HD ... 124
Figure 84: Differentiation of uptake in brown fat from supraclavicular lymph nodes ... 124
Figure 85: Monitoring therapy response by PET/CT in HD ... 130
Figure 86: Monitoring therapy response by PET/CT and adaptive therapy in NHL ... 131
Figure 87: Assessment of residual lymphoma mass after completion of therapy by PET/CT ... 132
Figure 88: Sparing normal parotid gland while planning radiation field for NPC ... 138
Figure 89: The GTV variation consequent to PET/CT registration in right parotid cancer case ... 139

List of Tables

Table 1: Commonly Used PET Scintillator Detectors And Their Properties 12

Table 2: Radioactive Isotopes Used In PET Imaging 16

Table 3: Suggested Response Measurement Parameters Using SUV 48

Table 4: TNM Staging Of Nasopharyngeal Carcinoma 67

Table 5: Stage Grouping Of Nasopharyngeal Carcinoma 68

Table 6: TNM Staging Of Oropharyngeal Carcinoma 78

Table 7: Stage Grouping Of Oropharyngeal Carcinoma 79

Table 8: TNM Staging Of Laryngopharyngeal Carcinoma 85

Table 9: Stage Grouping Of Laryngopharyngeal Carcinoma 87

Table 10: TNM Staging Of Salivary Glands Malignancies 95

Table 11: Stage Grouping Of Salivary Glands Malignancies 96

Table 12: TNM Staging Of Thyroid Cancer 107

Table 13: Stage Grouping Of Thyroid Cancer 108

Table 14: Cotswold-Modified Ann Arbor Staging Of Lymphoma 120

Table 15: Revised Criteria For Therapy Response Assessment Of Malignant Lymphoma... 127

Table 16: Recommendations For Post-Treatment Assessment Of HD And NHL.... 132

List of Abbreviations

2D: Two Dimensional

3D: Three Dimensional

AC: Attenuation Corrected

BMB: Bone Marrow Biopsy

BTV: Biological Target Volume

C cells: Calctonin Producing Cells

CEA: Carcinoembryonic Antigen

CR: Complete Remission

CRu: Complete Remission Unconfirmed

CT: Computed Tomography

CTV: Clinical Tumor Volume

CUP: Carcinoma Of Unknown Primary

DTC: Differentiated Thyroid Cancer

FBP: Filtered Back Projection

FDG: Fluoro-Deoxy-D-Glucose

FNAC: Fine Needle Aspiration Cytology

FOV: Field Of View

GCS-F: Granulocyte Colony Stimulating Factor

GLUT: Glucose Transporter

GTV: Gross Tumor Volume

HD: Hodgkin Disease

IMRT: Intensity Modulated Radiotherapy

IWC: International Workshop Criteria

LOR: Line Of Response

MALT: Mucosa Associated Lymphoid Tissue

MEN: Multiple Endocrine Neoplasia

MIP: Maximum Intensity Projection

MLC: Multileaf Collimator

Mo: Months

MRI: Magnetic Resonance Imaging

MTC: Medullary Thyroid Cancer

NAC: Non Attenuation Corrected

NHL: Non Hodgkin lymphoma

NPC: Nasopharyngeal Carcinoma

NPV: Negative Predictive Value

OS: Overall Survival

OSEM: Ordered-Subsets Expectation Maximization Algorithm

PD: Progressive Disease

PET/CT: Combined Positron Emission Tomography And Computed Tomography

PET: Positron Emission Tomography

PFS: Progression Free Survival

PHA: Pulse Height Analyzer

PMT: Photomultiplier Tube

PPV: Positive Predictive Value

PR: Partial Remission

PTV: Planned Target Volume

ROI: Region Of Interest

RTP: Radiotherapy Planning

SCC: Squamous Cell Carcinoma

SD: Stable Disease

SPD: Sum Of The Products Of The Greatest Diameters

SUV max: Maximum Standardized Uptake Value

SUV: Standardized Uptake Value

Tg : Thyroglobulin

TgAb: Thyroglobulin Antibodies

TSH: Thyroid Stimulating Hormone

US: Ultrasonography

WBS: Whole Body Scan

Zeff: Effective Atomic Number

Introduction

&

Aim of Work

INTRODUCTION

Positron emission tomography (PET) is a molecular imaging technique in which positron-emitting radionuclide tagged tracer molecules are used to trace a biologic function within the body. It can provide valuable information about different pathologic as well as physiologic processes, depending on the type of used radiotracer. **(Rohren et al, 2004)**

The major clinical application of PET is in oncology, using 18F labeled fluorodeoxyglucose (18F-FDG). By this way, it gives quantitative and qualitative functional information about tumor cells depending on their increased rate of glucose metabolism. 18F-FDG PET is regarded to be effective in detection, staging and restaging of malignancies with a remarkable high sensitivity. Its major limitations have been the lack of anatomical landmarks, relatively blurred images and limited spatial resolution. **(Rohren et al, 2004)**

In the last decade, the ***combination of PET and computed tomography (PET/CT)*** has been introduced in the field of oncologic imaging. Combined PET/CT represents a very unique imaging modality that scans the whole body in the same session, providing functional and anatomic information in co-registered images. It combines the high sensitivity of PET to the superior anatomical localization by CT resulting in much more accurate detection and staging of malignancies. It also provides a better quality PET images due to better attenuation correction by CT scan in a relatively short time. **(Von Schulthess et al, 2006)**

Accordingly 18F- FDG PET/CT has acquired a firm place in the evaluation of malignancies. It is rapidly becoming the key investigative tool for the loco-regional staging and detection of distant metastases. It has a quite greater role in assessment of recurrence and differentiating it from post therapeutic tissue changes. It has also gained widespread acceptance as a key tool used to demonstrate early response to therapy before other markers of response. PET/CT impacts the patient’s prognosis by altering the management strategy according to the obtained findings during the initial staging or the follow up (during the course of treatment or later follow up). **(Ben-Haim and Ell, 2009)**

PET/CT is strongly applied in the head and neck malignancies, the most common of which are squamous cell carcinoma of the upper aero-digestive tract, salivary and thyroid glands malignancies in addition to lymphomatous deposits. It can be added to the work up of carcinoma of unknown origin or to guide biopsies. Furthermore, PET/CT potentially supports tumor volume delineation in radiation therapy planning in the head and neck where a multitude of sensitive structures is confined to a small area of the body. **(Poeppel et al, 2009)**

AIM OF WORK

The focus of this study is introducing the principles of 18F-FDG PET/CT imaging with emphasis on its clinical applications in the most common head and neck malignancies in addition to its potential pitfalls and limitations.