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Recent Modalities in the Diagnosis of Obesity

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Obesity has been an emerging health problem worldwide which has a major impact on public health. It is associated with medical, psychosocial and economic implications with increasing prevalence among both adult and paediatric population. Obesity led to an increased risk of medical conditions like diabetes mellitus, hypertension, coronary artery disease, insulin resistance and sleep apnoea. Obesity has a major impact on cardiovascular system causing structural and functional changes leading to cardiac dysfunction.

Hence it is important to diagnose obesity at the earliest for timely prevention of associated complications. Apart from routine diagnostic methods for obesity like body mass index, anthropometry (waist circumference, hip circumference, neck circumference), several recent modalities were described for the diagnosis of obesity like radioimaging, nuclear medicine imaging which will be described in detail in this review article.

MRI (Magnetic resonance imaging) aids in the detection of adipose tissue at various sites and organs, whereas MRS (Magnetic resonance spectroscopy) helps in mapping of small quantity of lipids. MRI helps in delineating ectopic adipose tissue accumulation establishing that obesity alone is not a major cause for derangement in metabolic profile. An additional advantage is MRI brain is

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an excellent imaging guide for studying the role of central appetite regulatory systems in the occurrence of obesity.
Sonography is not accurate in the estimation of hepatic steatosis. But advancements in sonographic modalities gives an extra edge in evaluation of hepatic steatosis by availing special physical characteristics such as stiffness of adipose tissue and its sound absorption.
Positron Emission Tomography (PET) (Nuclear medicine imaging) helps in studying central pathophysiology, activity of brown adipose tissue and disruption of gut-brain homeostasis.

Keywords: Obesity; anthropometry; imaging; MRI; ultrasound; nuclear medicine; spectroscopy.

1. INTRODUCTION

Obesity has been an emerging public health problem leading to several metabolic abnormalities and increasing obesity is associated with increased prevalence of metabolic syndrome (MS). Obesity and MS together cause cardiovascular dysfunction leading to increased morbidity and mortality.

Obesity is an independent risk factor for Non communicable diseases, hence it is important to prevent, diagnose and intervene obesity at the earliest for the reduction of future health costs and consequences. Previously obesity was assessed on the basis of mere body weight. Heavier and bigger persons were considered to be 'obese' on the basis of muscularity even without the presence of fat deposits. Later on, several studies had proved that body weight is not an exact measure of body composition [1].

As abdominal obesity is one of the crucial foreboding factor leading to metabolic syndrome, there is rising indagation in obese subjects regarding adipose tissue (AT) distribution in the body. Several studies had proved that distribution of adipose tissue at various sites of the body is more important than the amount of total fat deposition since abdominal (visceral) obesity is more commonly associated with increased risk of chronic medical co-morbidities. Various techniques can be assorted to diagnose obesity like anthropometric measurements and advanced radiologic imaging modalities. Both traditional anthropometric measurements and the recent imaging modalities have advantages and disadvantages.

Imaging plays a crucial role in the diagnosis and management of many medical conditions. In the obese population, the ability to get diagnostic quality images and the ability to perform image-guided interventions can be technically challenging [2].

A better awareness is essential for both radiographers and the students regarding the difficulties in imaging obese patients. Location of anatomical organs and other structures should be precisely identified for accurate diagnosis and also for estimation of radioactivity. Proper knowledge in this aspect helps in reducing anatomical attenuation and artefacts. Identification of modifications from the routine imaging techniques in obese patients is the most important step in the diagnosis of obesity [3].

2. ANTHROPOMETRIC INDICATORS AND THEIR IMPLICATIONS: A NONINVASIVE TOOL FOR THE DIAGNOSIS OF OBESITY

Anthropometric indices have been considered as indicators for risk detection, intervention and assessment of nutrition and health status. Hence they are aptly labelled as "Anthropometric Health Indicators (AHIs)". Approximately 17 AHIs were described that can be estimated with the help of 3D human images. These are non-invasive methods to diagnose obesity compared to several other imaging modalities. In addition, these are easily affordable then the latest expensive techniques Various methods and techniques were proposed by several authors with specific cutoffs for different groups of subjects based on which the reliability of an AHI was estimated. However the analyses of these studies were not fully proved efficacious and valid [4].

Traditionally, measuring tapes have been used for circumferences & lengths. For measuring volumes, air and water displacement methods were used. Main AHIs used for the diagnosis of obesity are weight, height, waist circumference, hip circumference, thigh circumference, neck circumference and other volumes and surface areas which were further classified into sub categories.

However, these techniques require well-trained personnel. Besides there is high chance of measurement errors making AHIs poorly reliable for diagnosis of obesity and other medical conditions.

2.1 Body Mass Index (BMI)

It is a simple and most commonly used indicator for diagnosis of obesity. It can be calculated as the ratio between body weight in kg and height in square meters. Any increase or decrease in BMI leads to chronic medical conditions especially affecting cardiovascular system.

2.2 Waist Circumference (WC)

It is particularly helpful in the evaluation of visceral fat. However several different ways and protocols are being followed by different study groups for the measurement of waist circumference regarding the level of measurement. It is one of the most important criteria for the diagnosis of metabolic syndrome. Studies had proved increased risk of CVD and type 2 diabetes mellitus with an increase in WC leading to an increase in cardiovascular morbidity and mortality.

2.3 Waist-to-Hip ratio (WHR)

It is an indicator of visceral adipose tissue deposition. Hip circumference can be measured at the level of maximum projection on the posterior aspect of the body (buttocks). Similar to WC, an increase in WHR also led to an increased risk of CVD and type 2 DM [5].

2.4 Waist-to-Height Ratio (WHtR)

It is an indicator and measure of distribution of adipose tissue in the body. Hence it is called “Index of Central Obesity”. It is considered as a better indicator of metabolic risk compared to BMI and WC. An increase in WHtR leads to an elevated risk of cardiovascular diseases, diabetes, hypertension, deranged lipid profile leading to increase in mortality.

2.5 Body Fat Percentage (BFP)

It is the amount of fat mass as a % of total body mass. It can calculated from body density using standard age and sex specific equations. Body density is measured as a ratio between body mass and volume. Body volume can be obtained from with the help of MRI, CT, air displacement plethysmography or 3D scans. Several studies had proposed a variety of methods to measure BFP. BFP can also be measured using skin fold thickness, whole body silhouettes from DEXA scans(commonly used in pediatric population). Increase in BFP is associated with increased risk of metabolic syndrome, cardiovascular disease and reduced survival [6].

2.6 Conicity Index (CI)

It is highly accurate in the assessment of central obesity by studying the distribution of adipose tissue at various body sites. It can be calculated using the formula,

$$Conicity\ Index\ (CI) = \frac{WC\ (m)}{0,109\sqrt{\frac{Weight\ (kg)}{Height\ (m)}}}$$

Fig. 1. Showing equation for Conicity index

Increase in CI is associated with high incidence of metabolic syndrome. Although no direct correlation has been proved between CI and cardiovascular mortality, it helps in estimating the risk of diabetes and hypertension in future [7].

2.7 Sagittal Abdominal Diameter (SAD)

It is also called Abdominal height. It is a better measure of abdominal VAT deposition than BMI and WC. Anteroposterior diameter of abdomen is measured in supine position with the help of abdomen calipers or other imaging modalities. There is a proven role of SAD in the occurrence of metabolic syndrome and insulin resistance. Hence SAD is a good indicator of glucose dysregulation. Increase in Sad is also associated with CVD and increased risk of dementia [8].

2.8 Abdominal Volume Index (AVI)

It helps in estimation of whole abdomen volume using WC and HC using the formula,

$$AVI = \frac{2(WC)^2 + 0.7(WC - HC)^2}{1,000}$$

Fig. 2. Showing equation for Abdominal volume index

AVI helps in prediction of diabetes and is associated with disruption of glucose homeostasis, diabetes, CVD and overall mortality.

2.9 Visceral Adipose Tissue Area (VATA)

It is the measure of adipose tissue surrounding the visceral area most common site being around umbilicus. CT and MRI are helpful for measuring VATA. It helps in precise estimation of fat depot. VATA has been shown to be associated with increased risk of coronary plaques and coronary stenosis.

2.10 Fat Free Mass Index (FFMI)

It is associated with muscle mass. It can be calculated using the formula,

$$FFMI\left(\frac{kg}{m^2}\right) = \frac{FFM\ (kg)}{Height^2\ (m^2)}$$

Fig. 3. Showing equation for Fat Free Mass Index

Free fat mass can be calculated by subtracting fat mass from body mass. FFMI is an indicator of nutritional status [9].

2.11 Neck Circumference (NC)

It helps in evaluation of distribution of SCAT in the upper body. It is measured at the level just below the Adam's apple. This measure is used both in children and adults. It is considered as an independent risk factor for cardiometabolic diseases [10].

2.12 Fat Fraction (FF)

It is a quantitative image based biomarker for the diagnosis of obesity defined as ration of signals from fat protons to the total signal arising from both fat and water ptotons.

2.13 3D Scanning Systems

3D scanning systems help to study the distribution of adipose tissue at various body sites which in turn helps to evaluate the effects of obesity on normal health. Circumferences, volumes and surfaces can be measured with the help of novel 3D scans which works on the basis of optical scan system. With increased public health awareness, 3D scans are now in rise [11].

2.14 Advantages of Anthropometric Assessment

Anthropometric indicators are accurate in estimating visceral fat, easy to use, economical method for nutritional assessment and diagnosis of obesity. They are also helpful for early prediction of associated complications of obesity.

2.15 Limitations of Anthropometric Assessment

- Possibility of measurement errors in obese patients due to discrepancies in locating anatomical landmarks.
- Use of different techniques in various studies.
- Some of the parameters require complex calculations.
- Lack of standardization of the techniques used.

2.16 Radiologic Imaging of Adipose Tissue

DEXA considers fat and lean soft tissue as the non-bony tissues in the body as two main energy peaks. However this modality cannot differentiate SCAT and VAT. In addition to that, disadvantage is that it involves minor radiation exposure.

CT delineates fat tissue from non-fatty tissue. It can differentiate SCAT and VAT. However there is maximal exposure to radiation.

Magnetic resonance imaging (MRI) and spectroscopy (MRS) helps to quantify fat tissue at various body sites and also to study the fat distribution in the body [12]. The main advantage is that there is no radiation exposure in this imaging modality.

2.17 Magnetic Resonance Imaging (MRI)

2.17.1 Relaxation-based MR techniques

In MRI, fat and lean tissues are depicted by specific "longitudinal and transverse relaxation times" (T1 and T2), which differ among various organs, however they are to be constant in adipose tissue. In a T1-weighted image, fat tissue appears brighter than other tissues. The volume of issue compartment under focus can be obtained from the MR images and its distribution can also be studied by planimetric methods.

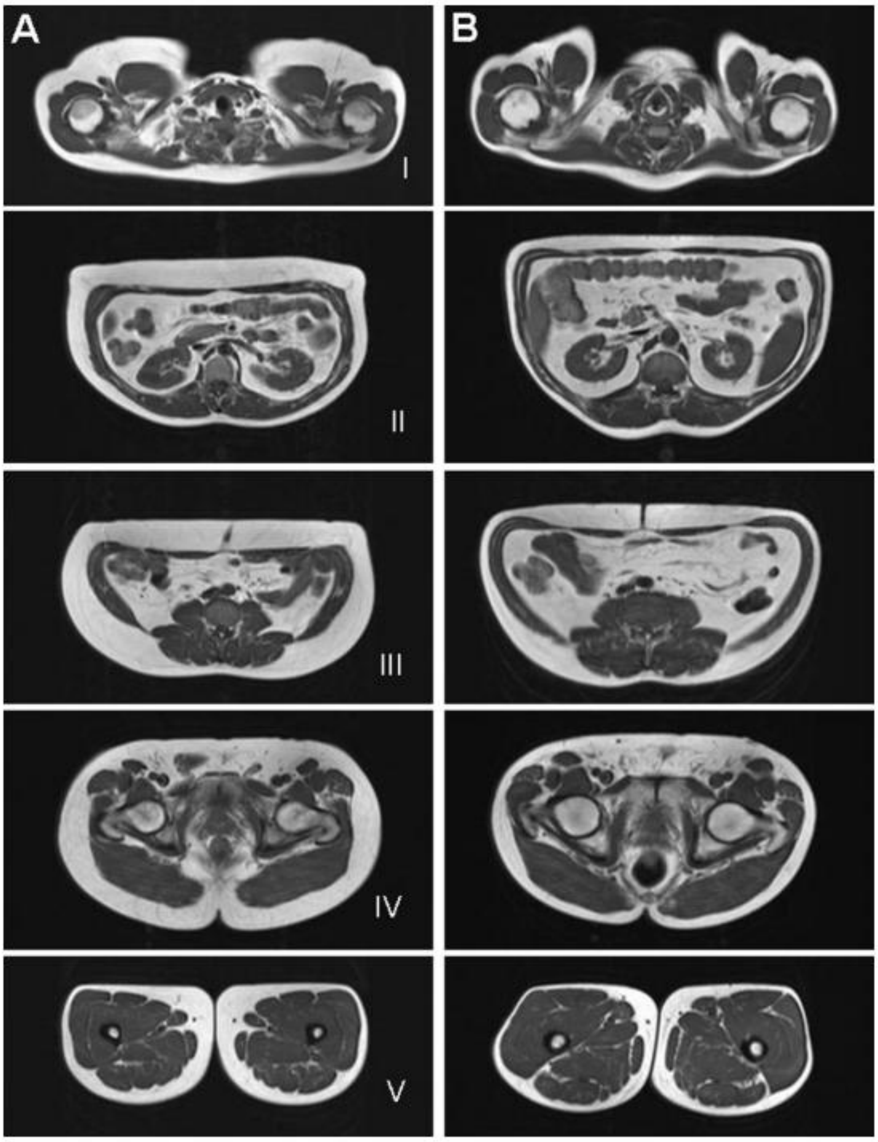

Fig. 4. Axial T1-weighted images of two male subjects with nearly identical BMI and WHR but different adipose tissue distribution. (A) High amount of SCAT, lower VAT, (B) high VAT but lower SCAT.

2.18 Phase Sensitive MRI

This works on the principle of 'chemical shift', i.e. difference in frequency between water and methylene protons (215 Hz at 1.5 Tesla). The advantage of phase sensitive MRI is that it is capable of quantifying even smaller amounts of adipose tissue.

2.19 Fat Selective MRI

This works by suppression of water signal or accentuation of fat signal at a specific frequency. However this method is not useful for estimation of low quantities of fat tissue due to increased risk of artefact formation [13].

2.20 Proton Magnetic Resonance Spectroscopy (1 H-MRS)

This modality is useful to assess lipids with a lesser volume share in the parenchyma of organs like liver and skeletal muscle. It works on the principle of different frequencies of H protons on the basis of which they bind to different molecules [14].

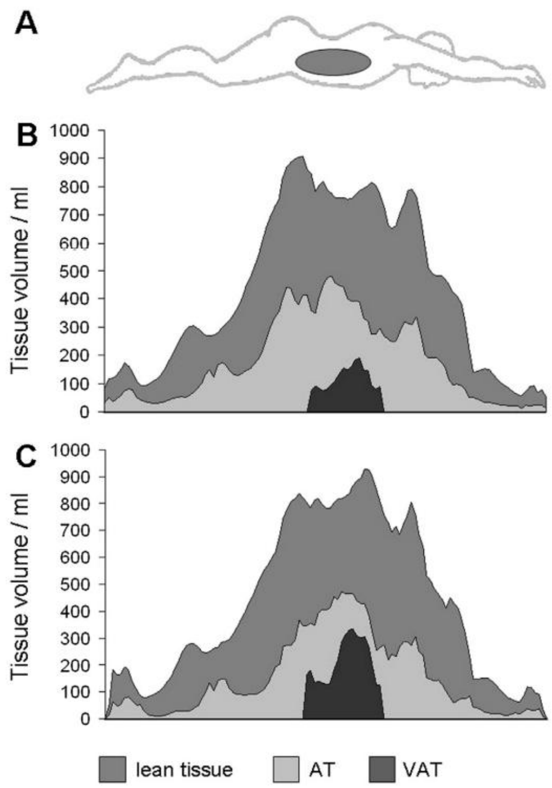

Fig. 5. (A) Sketch of the position of the subjects in the MR scanner. (B)Whole body tissue profiles of two males indicating distribution of lean tissue, adipose tissue and visceral adipose tissue. Subject in (B) has clearly lower VAT and higher SCAT than subject (C).

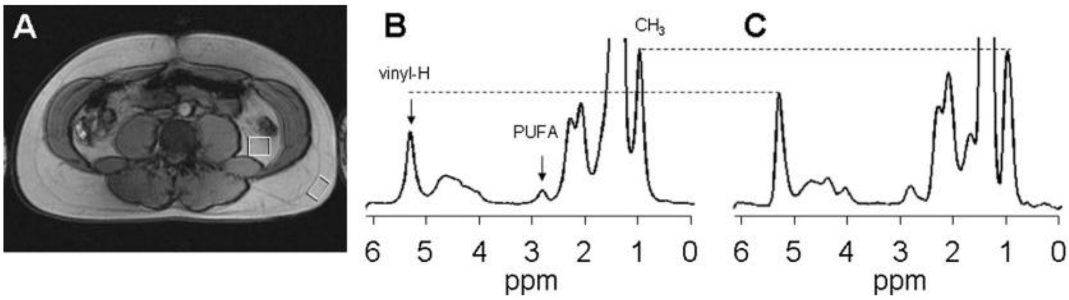

Fig. 6. Axial T1-weighted image of the abdomen with indicated volumes of interest for spectroscopic examinations in VAT and superficial SCAT. Spectra of VAT (B) and superficial SCAT (C) show clear differences in composition of fatty acids with VAT having a lower amount of unsaturated fatty acids.

2.21 H-MRS for Quantification of Hepatic Lipids

Major metabolites of a normal liver are water and methylene at 4.7 and 1.3 ppm respectively. Breathing aggrevates liver examination (both morphologic and spectroscopic). Examinations in expiration helps to decrease artefacts caused by air in the lungs. Here two different spectra in 7^{th} segment of liver are depicted, one from a female with low lipid concentration and the other from an obese male (fatty liver). Hepatic lipids are quantified as %, by measuring lipid:water ratio signal [15].

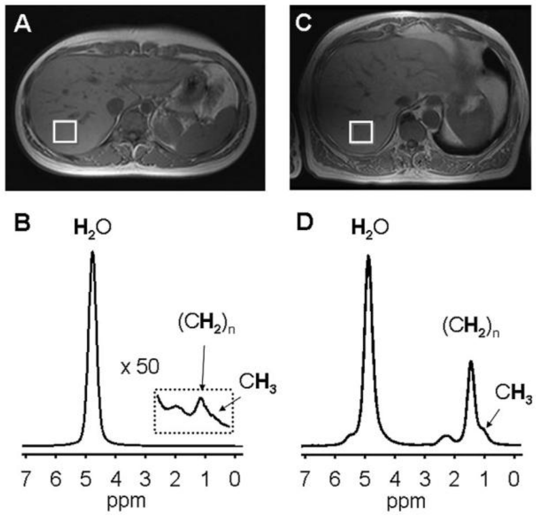

Fig. 7. Axial T1-weighted images of the liver with indicated volume of interest for spectroscopic examination in posterior part of segment 7 of a female (A) and a male subject (C). Corresponding spectra reveal low amounts of HL in the female subject (B) showing that even contaminations of <1% can be assessed, and the male (D) with obvious fatty liver.

2.22 H-MRS for Quantification of Intramyocellular Lipids

The characteristic of muscle spectra is the ability to differentiate two lipid compartments, extramyocellular lipids, EMCL (lipids in adipocytes around the muscle fibres and intramyocellular lipids, IMCL (located within the cytoplasm of myocytes), out of which IMCL is metabolically active. EMCL has non-homogeneous distribution causing signal interference. Fig. 8 depicts tibialis anterior muscle spectra from two obese males with grossly varied quantity of IMCL. Creatine signal was considered as a reference here. It was shown that insulin sensitive persons have low (e.g. Fig. 8B) and insulin resistant persons have high quantity of IMCL (Fig. 8D). However this differs in trained athletes/sportsmen with high IMCL which is used during exertion which shows the rapid regulation of IMCL due to food patterns and exercise [16].

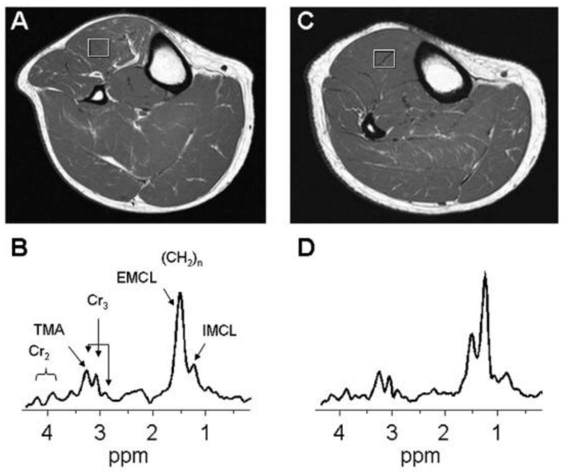

Fig. 8. Axial T1-weighted images of the lower leg with indicated volume of interest for spectroscopic examination in the tibialis anterior muscle from an insulin sensitive obese male (A) and an insulin resistant obese male (C). Spectra show a low amount of IMCL and high EMCL in (B) and high IMCL/low EMCL in (D).

2.23 Dixon's Method

It is an MR based simple proton technique described by WT Dixon in which water and fat images are obtained separately. Major drawback with this technique is inhomogeneity of the magnetic field [17].

2.24 Magnetization Transfer Imaging

This is a technique in which radiofrequency energy is applied to explore the contrast between different tissues like water and fat used in the diagnosis of obesity. Saturation of protons bound to macromolecules is observed whereas protons in free water are not saturated. These differences in signal achieved is called 'Magnetization transfer' [18].

2.25 MRI of the Brain: Central Markers of Obesity

Human brain structure and its connections play a role in obesity which can be detected by MRI. Brain mater can be quantified compartment wise in terms of volume and density by T1 weighted images [19]. Many previous studies proved that low brain volume has correlation with obesity. Obese subjects showed lower volume of grey matter than lean & overweight people, and lower volume of white matter than the overweight [20].

2.26 Sonography

Obesity affects the diagnostic accuracy of sonography by creating non-diagnostic artefacts leading to need for CT/MRI evaluation increasing the cost of health care. Image quality is affected due to distant location of internal organs from the skin and attenuation of ultrasound waves by adipose tissue in cases of extreme obesity. This leads to a diagnostic confusion, or sometimes complete missing of diagnosis due to poor visualization due to impedence by the adipose tissue. This is particularly important in antenatal ultrasonography for precise visualization of fetal profile.

On the other hand, fat becomes the focus of imaging in case of quantification of fat in hepatic steatosis which can be visulaized as accentuated echogenicity reflecting altered liver parenchyma.

Advancements in sonographic modalities gives an extra edge in evaluation of hepatic steatosis by availing physical properties such as stiffness of adipose tissue and its sound absorption and speed [21]. Even though elastography has a proven role in detecting hepatic fibrosis, it cannot assess steatosis due to poor correlation with liver stiffness. Advanced method gain ground in estimating grade of hepatic steatosis is Controlled Attenuation Parameter (CAP) which works on the technique of elastograhy to detect attenuation of ultrasound waves.

Certain limitations were noted in the diagnosis of obesity by radioimaging like poor penetration of X-rays, artefacts caused by movement of the patient, ultrasound wave attenuation, disturbances in the field of view. There can be subjective variations among the radiographers and radiologists in the measurement of adipose tissue deposits.

2.27 Obesity and Nuclear Medicine Imaging

Obesity affects Nuclear medicine imaging modality as well. It depends on quantification of radioactivity by measuring the radiopharmaceutical activity. Subjects with more weight receive higher dose of [18F] fluordesoxyglucose (FDG) activity which implies higher radioactivity. However, there is a high possibility of attenuation artefacts due to improper positioning, altered positioning and delayed static images [22].

PET neuroimaging along with MRI together provide quantitative assessment of obesity. PET imaging in obese people have shown unavailability of dopamine receptor in the striatum in comparison with lean controls [23]. It helps in detection of brown adipose tissue activity. PET studies are still in process to detect the role of serotonergic, norepinephrine system, and in the obese persons who need bariatric surgery.

2.28 Technical Challenges in Radioimaging of Obesity

Inspite of better technical advancements in radioimaging of obesity, obese individuals still pose a challenge regarding the quality of image and other aspects. Most important part in radioimaging is the part of the obese individual to be imaged and the size of the patient. There is a high risk of positioning errors that should be identified and corrected for precise diagnosis of obesity. Artefacts and attenuation errors should be taken care of. There are very limited studies that focus on radiographer's perspective of imaging and optimisation of radiography for precise and accurate assessment of obesity.

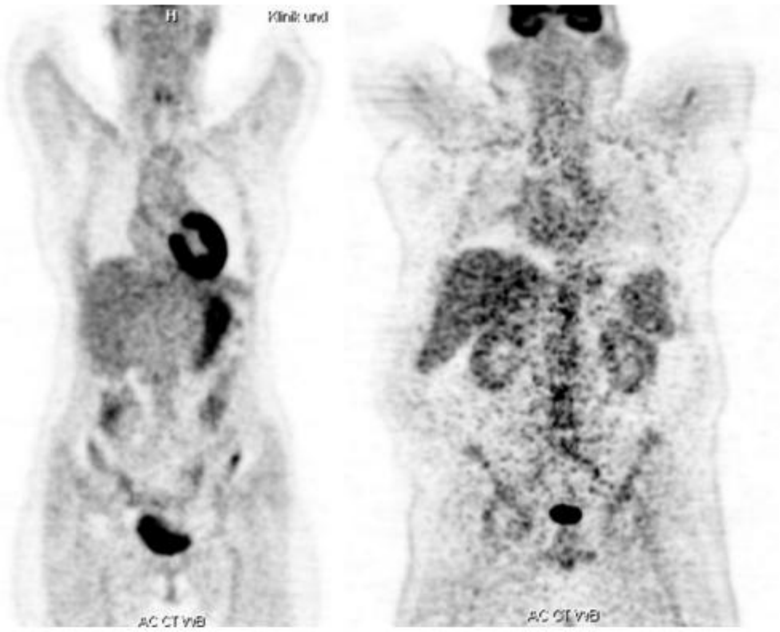

Fig. 9. Whole-body PET scan of a normal-weight female (Body-Mass-Index, BMI, of 24.7 kg/m2) and an obese (non-diabetic) male patient (BMI 46.1 kg/m2) of comparable age (62 versus 59 years). Injected radiotracer activity was 323 MBq and 452 MBq [18F]FDG, respectively (3D acquisition, lutetium oxyortho-silicate crystals), and 3 min versus 4 min per bed position. Note the higher soft tissue activity in the obese patient, which hampers the scan interpretation and lesion detection together with higher soft-tissue attenuation.

3. CONCLUSION

Although several anthropometric indicators were described, no single indicator is adequately accurate for estimation of body fat and its distribution. Further more studies are needed in this aspect to study detailed body composition.

Recent modalities of imaging help in precise quantification of adipose tissue at various sites. MRI and MRS are useful to dileniate fat deposition at different sites of the body. Apart from quantification of fats, MRS also gives details regarding the composition of fatty acids in the fat tissue. MRI brain is an excellent imaging guide for studying the role of central appetite regulatory systems in the occurrence of obesity. Poor accuracy of sonography in the estimation of hepatic steatosis lead to the evolution of newer methods of sonography which take into consideration special physical properties of fat tissue like stiffness and its sound absorption. Nuclear medicine imaging methods especially PET detects brown adipose tissue activity.

Early and accurate diagnosis of obesity plays a crucial role in prevention of complications associated with obesity which in turn reduces morbidity and mortality.

CONSENT

As per international standard or university standard, patient’s written consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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