Obesity Medicine 16 (2019) 100150

Contents lists available at ScienceDirect

Obesity Medicine

journal homepage: www.elsevier.com/locate/obmed

Review

Evaluation of body composition parameters using various diagnostic methods: A meta analysis study

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ARTICLE INFO

Keywords:
Body composition
Obesity
Fat mass index
Total body water
Adipose fat tissue
Visceral fat tissue

ABSTRACT

Aim: The systematic study aims to provide a brief summary of existing techniques and technological advances used for measuring the body composition in an individual.

Methods: The different techniques used for the assessment of body composition parameters were discussed in the study as follows: densitometry, plethysmography, isotope dilution, whole body ^{40}K counting, anthropometric, bioelectrical impedance analysis, ultrasound, DEXA, CT, MRI and thermal imaging.

Results: In the thermal imaging method, the percentage difference in abdominal skin temperature between normal and obese subject was found to be 4.45%. In ultrasound imaging, we obtain three bands of white layers which act as an interface between skin-fat, fat-muscle and muscle-bone. The subcutaneous fat tissue and muscle thickness was measured as 4.23 mm and 31.75 mm respectively. The MRI of an abdomen region was performed at the site of the L3-L4 disc and the subcutaneous adipose tissue volume was measured as 1955.11 cm3.

Conclusion: The proposed study summarises the benefits and drawbacks of different techniques, as each technique has its own pros and cons. Among the imaging modalities studied, non-invasive imaging method such as thermal imaging and ultrasound was found to be a feasible imaging technique for the assessment of body composition in an individual.

1. Introduction

Excessive body fat has been significantly associated with health-related problems. The increase in obesity among adult and children has emphasized the importance of body fat with regards to long term health. World Health Organisation (WHO) has estimated that globally, 1 billion i.e.16% of adult is overweight, out of which 5% falls into the category of obese (World Health Organization, 2018). In India, the prevalence of obesity is 26.6% in women and 9.3% in men. More than two million cases of child obesity per year get recorded each year. It was reported that India had the third largest population of obese people, after the United States of America and China (Ahirwar and Ranjan Mondal, 2019). The percentage of obese children is 10–20% and it increases up to 30% in adolescence due to sedentary lifestyle (Ahmad et al., 2010). According to National Family Health Survey (NFHS-4), the number of obese people has doubled in India over the past 10 years. People with obesity possess a high risk of acquiring disorders such as type II diabetes, Osteoarthritis, Coronary artery disease, pulmonary diseases etc (World Health Organization, 2015). Therefore assessment of body composition (BC), especially fat and fat free mass (FFM) plays a very crucial role in assessing health related condition in an individual. Hence BC provides clear information of percentage of fat, bone mass, water content and muscle volume in an individual.

The different techniques used for the assessment of body composition parameters are given as follows: densitometry, plethysmography, isotope dilution, whole body ^{40}K counting, anthropometric, bioelectrical impedance analysis, ultrasound, DEXA, CT, MRI and thermal imaging. The accuracy of different BC technique available is directly proportional to the number of body component it measures. It consists of two components BC which involves in the measurement of fat mass and FFM. Then a three component BC will measure fat mass, FFM and lean tissue mass. There also exist a four component BC whose measurements are based on fat mass, total body water (TBW), bone and proteins (Pate et al., 2012).

The validation of the BC measurements is performed by comparison of the obtained result with the standard reference value. Accuracy and precision plays a very important role in determining error-free diagnosis and in classification of deviant BC in an individual. The precision of the technique is validated by evaluating the degrees to which the result remains persistent with repeated measurement under constant condition. (Clodagh et al., 2015). The main intent of this study was to discuss about the basics, working principle, advantages and

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https://doi.org/10.1016/j.obmed.2019.100150
Received 25 July 2019; Received in revised form 3 October 2019; Accepted 7 October 2019

disadvantages of most frequently used technique for BC analysis.

2. Material and methods

2.1. Hydrostatic weighing (densitometry)

Hydrostatic weighing is also known as densitometry as well as underwater weighing. In this technique the body's density is measured by obtaining the difference of body weight in air and under water using Archimedes principle. The methodology includes measuring the weight of the subject (W_S) and density of tank water (W_D). Then the subject is made to sit on a specialized scale and submerged into a large tank of water. Next, the subject is asked to expel all the air from their lungs and the residual volume (RV) and the weight of the subject under the water (W_{SU}) is obtained. Then the density of the subject body is calculated using equation (1). Once the body density is obtained, body fat percentage can be calculated by utilising equation (2) (Siri, 1961).

$$\text{Body density} = W_S \,/\, [(W_S – W_{SU}) \,/\, W_D – RV] \quad (1)$$

$$\text{Body fat percentage} = [495/\text{body density}) – 4.142] * 100 \quad (2)$$

The body density and body fat measurement are repeated three times and average result is obtained. This technique was rarely used because of its inability to measure the adipose tissue or lean tissue accurately. This approach is also not suitable for children and especially for patients (Medical Research Council UK(a)).

2.2. Air displacement plethsmography (ADP)

Air displacement plethsmography technique was introduced by Behnke (Behnke et al., 1942) to overcome the drawbacks in the densitometry technique. This technique is commercially known as BOD POD. This technique has better precisions than the hydrostatic weighing technique and can be used for young children. The principle behind this technique is Boyle's law. In this technique the measurement of the body volume is obtained by air instead of water and by using the physical relationship between volume and pressure. The heart of the ADP unit is the dual chamber plethysmograph and an electronic scale. The computer is connected to ADP to retrieve the data using the ADP software (Ball, 2005).

Initially, the volume of air inside the closed empty chamber is measured. Then the subject is asked to sit inside the chamber. The body volume or density of the subjects is calculated based on indirect method by means of subtracting the volume of remaining air inside the chamber from the volume of air in an empty chamber. The measurement of the volume of air inside the chamber is carried out by applying a physical gas law known as Boyle's law (Medical Research Council UK(b)). Then by applying equations (3) and (4), we can measure the body fat and FFM percentage respectively (Siri, 1961).

$$\text{Body fat percentage} = [495 \,/\, \text{Density}] – 450 \quad (3)$$

$$\text{FFM percentage} = 100 – \text{body fat percentage} \quad (4)$$

However this method can be affected by variation in bone mineral content and hydration (water retention) in obese subjects. Varying bone mineral content and excessive fluid retention can increase or decrease the density of lean mass, and hence can lead to underestimation or overestimation of fatness respectively (Wells and Fewtrell, 2006).

2.3. Isotope dilution

Human body consists of 50–60% water which decreases to 40% in the case of obese adults. So if TBW is measured, then we will be able to measure fat free mass (FFM) and body fat mass. TBW includes both intracellular and extracellular water (Chamney et al., 2007). When a person intakes deuterium labelled water, it gets mixed with the body water within a few hours. This is called isotope dilution (Duren et al., 2008a; Medical Research Council UK(c)). In this technique, preparation of the dosage is a crucial step which depends upon the exact weight of D_2O consumed by the child. A 0.05 g of D_2O per kg of body weight is administered. If FTIR analyser is used, then 0.5 g of D_2O per kg body weight is administered to the subject. TBW can be measured by deuterium dilution, because deuterium (^2H or D) is a stable isotope of hydrogen. The baseline sample is collected (urine or saliva) in the container. The subject is then asked to empty their bladder and the subject weight is noted. The dose prepared in this technique is water labelled with ^2H (^2H_2O or D_2O, 99.8 atoms of %D). Then the subject is asked to drink the customised dose containing the known amount of D_2O. Then it takes 3–4 h for dose to equilibrate with body water. Then after 3 h, first post dose sample is collected through the urine sample and then after 0.5–1 h, the second post dose sample is collected. Then the analysis of fat mass (FM) and FFM is carried out by isotope–ratio mass spectrometry (IRMS) or Fourier transform infrared spectroscopy (FTIR) techniques (Medical Research Council UK(c); Lee and Gallagher, 2008).

Regardless of the accuracy and precise measurement of TBW especially when compared to BIA measurements, this technique suffers a disadvantage of administering a precise amount of the tracer dose to the subject. This technique is also expensive due to the sample collection, storage and proper analysis. This method was prone to high risk of cross contamination (Medical Research Council UK(c)).

2.4. Whole body ^{40}K counting

This method was first introduced in the year 1960s to predict TBW present in human body. Whole body potassium – 40 (^{40}K) isotope is a technique to measure the naturally occurring radioactive ^{40}K isotope in the body. In human body, a known amount of potassium 40 is found in intracellular water. The principle behind whole body ^{40}K counting is that the proportion of potassium (^{40}K) found in human tissue is persistent i.e. 0.0118% of total potassium. So by quantifying ^{40}K in human, the amount of total body potassium can be determined (Murphy et al., 2013).

The subject's natural radiation (^{40}K) is measured with the help of scintillation counters which is specialized to detect and measure ionizing radiation. During the ^{40}K measurement process, gamma rays are emitted by the potassium at 1.46 Mev which are detected by sodium iodide crystals in either single or multi-detector configuration. The measurement procedure was carried out for few minutes to an hour depending upon the scanning system (Kuriyan, 2018).

After the measurement of ^{40}K radiation, total body potassium calculation is carried out. FFM can be measured from the total body potassium which may vary in men and women. For men, it varies from 2.46 to 3.14 k per kg and in women from 2.28 to 3.16 k per kg of fat free mass. The TBF (total body fat) can be calculated by subtracting FFM from body weight of the subject. Although this technique has a high accuracy still it is very rarely used because of its cost and requirement of specific environment for implementation (Wang et al., 2007; Medical Research Council UK(d)).

2.5. Anthropometric measurement

The word anthropometric is derived from a Greek word, ‘anthropos’ meaning ‘human’ and ‘metron’ meaning ‘measurement’. In this method, size, proportion and composition of the human body are assessed to obtain the anthropometric measurement. It includes weight, height, recumbent length, waist and hip circumferences, skin fold thickness etc to assess the body fat. These measured parameters can be combined with each other to calculate the anthropometric indices. Then these indices can then be assessed to come into a conclusion regarding the subject's BC, growth and development. The adult BMI threshold values according to WHO were given in Table S1 (Wells, 2014). Table S2 indicates the BMI percentile threshold in children for obesity classification as suggested by WHO. The nutritional status is usually referred based on BMI percentile (Chung, 2015).

2.5.1. Body mass index (BMI)

BMI is a traditional method used for the measurement of BF% in an individual. Quetelet index or index of relative weight is obtained from mass and height of an individual. If a metric system is used for the measurement, then by dividing the weight in kilogram by height in meter squared (Siri, 1961), we obtain the calculated BMI as indicated in equation (5).

$$\mathrm{BMI} = \frac{\boldsymbol{weight}\,(\boldsymbol{kg})}{[\boldsymbol{height}\,(\boldsymbol{m})]^2} \tag{5}$$

If the measurement is carried out using pounds and inches, then the weight is taken in pounds and is multiplied by 703 and then is divided by height in inches squared (World Health Organization Expert Consultation, 2004) as depicted in equation (6).

$$\mathrm{BMI} = \frac{\boldsymbol{weight}\,(\boldsymbol{lbs})\,\boldsymbol{x}\ 703}{[\boldsymbol{height}\,(\boldsymbol{inches})]^2} \tag{6}$$

BMI categories and cut off points are then used to guide the subject. Increased BMI level leads to elevated risk of obesity in individuals (Kwon et al., 2017).

Limitation of BMI includes the measurement of excess weight instead of excess fat. For example, woman usually tends to have more body fat than male with same BMI. Similarly an older individual tends to have excess body fat than a younger person for an equivalent BMI. In case of children, factors like height and level of sexual maturation influence the accuracy of BMI measurement. It is also regarded as a poor indicator of fat distribution and central obesity. Age, sex, ethnicity and lean mass influence is also responsible for low accuracy of BMI (Medical Research Council UK(e)).

2.5.2. Waist and hip circumference

Waist and hip circumference measurements are generally used to describe fat distribution as well as predicting body fat. The waist circumference is measured around the abdominal girth, over the midriff of the body between iliac crest and lower rib. In the case of hip circumference, the measurement is carried out over the widest region (greater trochanter) of hip region. For high precision, measuring tape with a spring attachment that maintains a fixed tension is used (Agarwal et al., 2009; Medical Research Council UK(f)). Waist and hip circumference value as well as their ratio can be interpreted using population specific cut off points. This technique being simple markers of adiposity, inexpensive and non invasive bears a limitation of poor discrimination of visceral from subcutaneous fat region. Due to this reason it becomes very challenging task to identify the correct anatomical site where the measurement can be carried out in obese individual. Most importantly, it was a difficult task to discriminate in the case of people with different BMI having same WHR (Medical Research Council UK(f); Mason and Katzmarzyk, 2009).

2.5.3. Skin fold thickness

Skin fold thickness measurement technique is a classical method to measure the subcutaneous fat fold in an individual. Since fat has a known density, the total and regional fat can be estimated on summing up the measurement of subcutaneous fat thickness across the region of interest (ROI). This technique is mainly used to assess subcutaneous fat at different ROI. Population specific equations are utilized in determining the percentage of body fat at specific region (Davidson et al., 2011; Medical Research Council UK(g)).

The skinfold thickness is measured using skinfold caliper and a non stretchable measuring tape. The skinfold caliper helps in measuring the subcutaneous fat thickness at specific site of interest. The measurements were performed at nine standardized anatomical sites of the body namely, chest, mid-axillary, flank, abdominal, quadriceps, triceps, biceps, subscapular and medial calf. Next the body density is calculated with the help of regional fatness obtained from skin fold measurements. Population specific equations are utilized for the conversion of raw skinfold thickness values into body fat percentage (Brozek et al., 1963) as shown in equation (7). It is very crucial to select the body fat estimating equation specific to ethnicity, race, age and gender (Medical Research Council UK(g); Boye et al., 2002).

$$\text{Body fat percentage} = (457 / \text{body density}) - 414 \tag{7}$$

Being inexpensive, non-invasive, portable and implementation of standardized protocol increases the validity of the skinfold thickness measurement. The limitation of this technique includes low accuracy and precision in case of obese subjects, due to difficulty in holding a large skinfold thickness in the caliper at specific sites. There is a notable decrease in the authenticity of the measurement with increasing thickness of the skinfold. Also hydration level can have a greater influence on the measurement, as there is a significant reduction of skinfold thickness due to lack of hydration in the subjects (Medical Research Council UK(g); Duren et al., 2008b; Freedman et al., 2013).

2.6. Bioelectrical impedance analysis (BIA)

Bioelectrical impedance analysis technique had been used as a commercially available device for the measurement of body fat content in the mid 1980s. BIA determines the electrical impedance which is further used to calculate TBW which is then used to measure FFM. Also, total body fat can be calculated by subtracting the fat free mass from total body weight (Stahn et al., 2012; Medical Research Council UK(h)).

In this technique the subjects body is modelled into a five level cylindrical compartments which include the trunk and four limbs while the fat in the body act as an insulator which makes a closed circuit (Kyle et al., 2004). Since fat mass has a much lower concentration of water in its tissue (about 10% water), it becomes poor conductor and lowers the signal from one point to another and as a result, high resistance is obtained. On the other hand, FFM tends to have higher concentration of water (20–75% water, muscle contains 75%), resulting in a lower resistance value. Therefore, higher resistance shows the presence of high fat mass and lower resistance shows the presence of FFM in the body which is then calculated by the system to obtain the physical values (Browning et al., 2010).

Regardless of the advantages, BIA suffers a limitation of poor accuracy in terms of severely obese state. Validity of BIA is also influenced by body size, gender, age, disease state and ethnicity. There also exists a tendency for BIA to overestimate BF% in very lean individual and underestimate body fat in obese subjects (Medical Research Council UK (h); Haroun et al., 2010).

2.7. Ultrasound studies

Ultrasonography or ultrasound is a non-invasive and radiation free technique used to measure visceral adipose tissue (VAT) and subcutaneous adipose tissue (SCAT). When the ultrasound waves pass from an adipose tissue region to a muscular tissue region, an echo is generated (Hernaez et al., 2011). This incoming echo is collected by the transducer and is converted back into electrical signals. The digital image of abdominal region is constructed by amplifying these incoming electrical signals. The intra-abdominal visceral and abdominal subcutaneous fat is measured by placing the transducer in the intercepting line between the xiphiod and waist circumference (De et al., 2013).

From the abdominal ultrasound images, VAT and SCAT thickness is recorded either in mm or in cm, after which a prediction equation is used to estimate abdominal fat tissues (De et al., 2010). This technique has an advantages of being portable, safe for all age groups, radiation free and can also be used in the case of severely obese subjects on the sites which are not acquiescent to skinfold measurement. Unfortunately, ultrasonography bears a limitation of lack of evidence on absolute validation, low sensitivity in diagnosis and is also subjected to intra-observer variability (Medical Research Council UK(i)).

2.8. DEXA

The lean tissue mass, total body fat, regional body fat and bone density were measured using the whole body dual x-ray absorptiometry (DEXA). The instrumentation of DEXA includes a source that initiates x rays at two different energies and a detector. The differential attenuation of the two energy peaks which are relative to each other is used in the calculation of bone mineral content, fat and lean soft tissue composition in the scanned area of interest. DEXA are specialized in differentiating the incoming pixel based on suitable models and relative attenuation into bone mineral, fat and lean soft tissue. One week prior to the DEXA scan, the subject should not have undergone any kind of scanning procedure such as contrast media scans, X-ray or CT (Rothney et al., 2009).

At the time of scan, the subject is asked to lie in a supine position on the scanning bed so that the scanning can proceed in a straight line from head to toe. The leg and feet should be positioned together with a strap around the ankles to prevent movement artefacts. Hands should be placed with palm facing the scanning bed, and the division from the thighs and the arms should lay inside the whole body scan boundary lines. The X–ray dose subjected to the body should be less than 5 μsv. Specific algorithms are used to estimate lean mass, fat mass and bone mineral mass. The data are stored in the database within the DEXA system (Hull et al., 2009).

The data extraction tool can be utilized to assess the raw data which is used for estimating TBW (g), LM (g), BC of tissues in specifically defined regions and the total bone mineral content (g). Limitation of DEXA includes trunk thickness, and differences in the hydration of the lean tissue along with age factor, may affect the accuracy of the measurement (Kaminsky et al., 2014; Medical Research Council UK(j)).

2.9. Computed tomography (CT)

CT technique is considered as a standard procedure to determine BC in an individual. The computed tomography has the ability to differentiate adipose and non-adipose fat tissue in the referred ROI (Klopfenstein et al., 2012). The whole abdominal region from the T10 - T11 to L4 - L5 disc site of the lumbar vertebrae is selected for the CT imaging. There always exists a known difference in the attenuation of X-rays between adipose tissue and visceral fat tissue. This difference is used to separate the two fat tissues and is used to determine the mixtures between them. Abdominal and liver fat can be accurately measured from a single slice using lower radiation doses which has renewed the interest in computed tomography (Bredella et al., 2010).

The main drawback of this technique is the exposure of subjects to radiation, which makes it unsuitable for pregnant women or growing children. It is also not advised for serial measurements in longitudinal studies (Medical Research Council UK(k)).

2.10. Magnetic resonance imaging (MRI)

Recently, the MRI technique has been used for assessing body fat distribution. The principle behind the MRI imaging was based on the magnetic property of hydrogen nuclei in water and fat which is present in the body cell to produce the soft tissue images of the whole body. MRI is used to estimate the volume of fat rather than the mass of subcutaneous adipose tissue and visceral fat tissue (Hu et al., 2016).

In this technique, the radio frequency is absorbed and emitted in the range of electromagnetic spectrum which helps in obtaining an image based on its spatial variation. Then pixels of adipose tissue, skeletal muscle and other tissue system component's pixels are estimated from the MRI image. Here pixel refers to the picture element which gets translated to respective tissue area (Karlsson et al., 2015). A three dimensional image was obtained using MRI technique to measure body fat content. The quantitative fat and water imaging was used to measure the regional adipose tissue and lean tissue (Reeder et al., 2012). The technical challenges in using this technique are that it has been recognized as the time-consuming and labor-intensive work in terms of manually segmenting the obtained abdominal scan images. Also this technique is very expensive to afford for the people living in rural areas and urban centres (Thomas and Bell, 2003).

2.11. Thermal imaging

Thermal camera uses infrared imaging for the measurement and visualisation of the thermal energy which are continuously emitted by the object to the surrounding. This specialized camera can discriminate temperature difference as small as 0.12 °C. Relative differences in the amount of heat dissipated by two different areas of the same ROI can be compared with the help of different thermal contours and patterns (Yosipovitch et al., 2007; Medical Research Council UK(l)). Infrared thermography was performed to study the temperature difference in obese and normal subjects. The images were taken using a thermal camera (FLIR A300) which is able to measure infrared radiation. As a result, it generates thermal images, in which each pixel corresponds to a particular temperature value. The participants observe acclimatization in the measurement room for at least 10 min before undergoing imaging procedure and the room temperature is maintained at 20° C. The subjects are advised to attain a comfortable position, by standing straight with no clothing on the abdominal region. The thermal images of the abdominal region is collected and stored for the studying the thermal pattern with the help of FLIR tool (Savastano et al., 2009).

3. Results

The proposed study focussed on comparing the different diagnostic modalities to evaluate the fat content in obese and normal subjects. Among the various diagnostic modalities, ultrasound, MRI and thermal imaging was found to be reliable diagnostic method for evaluating the obesity in individuals or study population.

The proposed study focused on ultrasound technique to measure the fat volume in humans. The subject has to lie down on a table with a section of the thigh exposed for the test. Then a sonographer, will apply a special lubricating jelly on to the thigh region, which helps in transmitting the sound waves.

Ultrasound imaging was performed at thigh region using widely available 4D scanners [chison Q bit 7, chison medical technology co Ltd, Jiangsu, China]. Fig. 1 indicates the presence of three bands of white layer. These white bands act as an interface between skin-fat, fat-muscle and muscle-bone. Then with the help of an electronic caliper, the points are marked at the boundaries of the tissue to be measured. By using the MicroDicom DICOM viewer, the subcutaneous fat tissue thickness is measured as 16.00 px which is equal to 4.23 mm, whereas the muscle thickness was calculated as 31.75 mm from 120.20px.

Next we focussed on MRI imaging modality to assess the obesity condition. For the MRI scan of the abdominal region, the participant was taken to the scan centre. The participant was asked to wear the hospital gown and lie in a supine position on the imaging bed. Extremity Siemens Medical MRI Scanners (Siemens 1.5T Symphony 8ch) was used to obtain the MRI images of the abdomen region. The MRI of an abdomen region is performed at the L3-L4 discs site and the slide thickness was maintained at 5 mm.

The imaging slides were analyzed using Mimics (Materialise Interactive Medical Image Control System, materialise, Belgium, Germany) software. Here each pixel is quantified by the Hounsfield unit (HU) of radioactive intensity and reflectivity. In the Hounsfield scale, zero represents the water density whereas the value of air and water

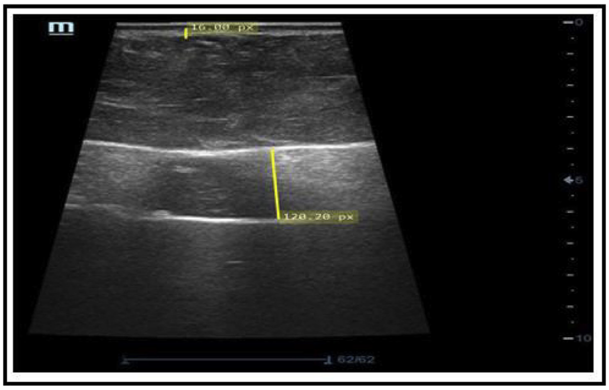

Fig. 1. Ultrasound image of the thigh region. The top line indicates the subcutaneous fat muscle interface. The centre white layer is the rectus femoris and vastus intermedius boundary. Whereas, the third white layer represent the muscle-bone boundary.

density is fixed at a value of −1000 HU and +1000 HU respectively. Fat density is fixed around −100 HU in the Hounsfield scale. The first step is to import all the abdominal MRI image which is of DICOM format. Fat is segmented from the overall abdominal MRI slices by creating a mask having a predefined threshold value of −205 HU to −51 HU. Then the 3D model of the fat is built by the process of dynamic region growing method, using eight connectivity with the seed point chosen at −100 HU. Then by using the distance tool, the volume of the subcutaneous fat tissue is measured and displayed on the computer screen.

In Fig. 2, the yellow pixel represents the muscle, solid organs, intestinal loops and vessels (Llewellyn et al., 2015). A violet pixel indicates the presence of subcutaneous adipose tissue, whereas the grey pixel represents the visceral fat tissue. The subcutaneous adipose tissue volume, measured in abdominal cross section is found to be 1955.11 cm^3.

Thermal images are obtained at the abdominal region for each subject as depicted in Fig. 3. After the image acquisition procedure, the stored thermal images were analyzed using FLIR software (version 2.0, FLIR Systems, inc., Wilsonville, US). The images are acquired in iron mode and temperature is measured using square tool of size 1 × 1 cm below the belly button for both normal and obese subjects.

The average skin surface temperature measured at abdominal region for obese and normal subjects were found to be 32.2 ^{O}C and 33.7 ^{O}C respectively. It is evident from figure that abdominal skin temperature of the normal subject is greater than that of an obese subject. This difference in temperature was generated due to the presence of the adipose tissue layer which acts as an insulating layer. This adipose tissue layer does not allow the heat transfer, resulting in the abdominal skin temperature to drop in the case of obese subjects.

4. Discussion

This study presents the overview of various clinical and imaging methods adopted for measurement of obesity in an individual. Anthropometry is one of the widely used methods for measuring obesity. BMI is one of the commonly used methods as it is strongly correlated with body fat levels. Many studies predicted that higher BMI indicates higher risk of chronic diseases. In spite of these advantages it fails to differentiate between body fat and lean mass. When the BMI values are fixed as same for both the genders, it is found that women tends to have more fat than men. However, WC (waist circumference), WHR (waist to hip ratio) and skinfold thickness are techniques which give good result but are very rarely used. Ultrasound technique is a safe method to measure the subcutaneous fat tissue volume and uses no radiation for the study. However, this technique requires a skilled operator for an accurate result.

The association between the BC and metabolic health can be well understood by DEXA, CT and MRI techniques. BIA is used widely in many studies for tracking BC in an individual over a period of time. Total body water (TBW), fat free body mass and body fat measurement can be determined by BIA. Other techniques such as densitometry, air displacement plethsmography, isotope dilution and whole body ^{40}K counting were used for measuring the fat content in the body. But due to the low accuracy of the output and new emerging technique with high precession, these techniques are now very rarely used.

Wagner et al. used body metric ultrasound instrument to obtain an image of the thigh region. In their result, three bright lines was obtained in which the subcutaneous fat was indicated by the top line. The bottom line represents the boundary between the muscle and the bone. Whereas, the centre line represent the presence of rectus femoris. The thickness of the tissue was obtained with the help of an electronic caliper. The output generated was comprised of 3.69 mm of measured subcutaneous fat and 32.0 mm to 46.6 mm of the muscle thickness (Dale, 2013). In this current study, we obtained the similar results in the ultrasound image in agreement with Wagner et.al findings. The measurements made in subcutaneous fat tissue layer and muscle tissue are found to be 4.23 mm and 31.75 mm respectively.

Chen J et al. selected a MRI slice of 5 mm thickness for imaging in abdominal region. For the quantification of fat, the lumbar region of level L3-L4 discs was selected. Lumbar L3-L4 discs region represents the upper abdomen and liver, which contains fat deposition and other regional fat tissue from the glutes region, can be eliminated (Hu et al., 2016). Steve et al. specified the measurement and separation of the different adipose tissue (subcutaneous and visceral) in the MRI images of abdominal region which can be obtained with the help of software such as Slicer 4.4.0. They implemented image segmentation on the MRI image of an abdomen using N4ITK algorithm and the volume of adipose

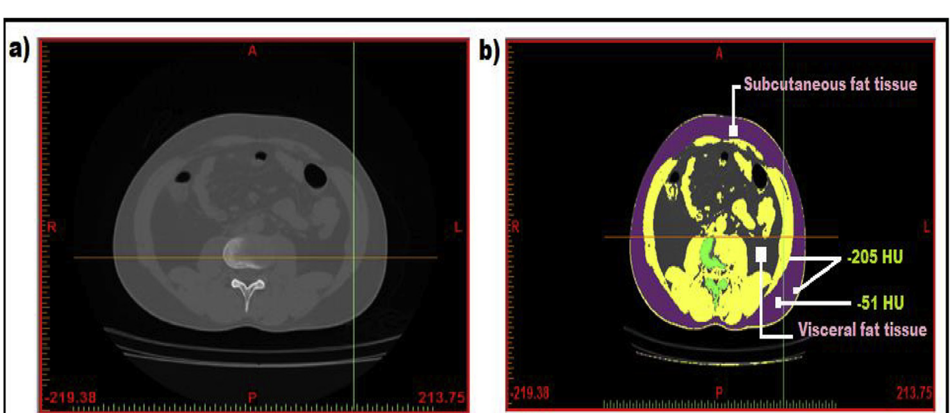

Fig. 2. a) Magnetic Resonance Image of an abdomen region. b) Segmented MRI of an abdomen region for fat measurement. The violet colour represents the subcutaneous adipose tissue and visceral fat tissue is represented by grey colour. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

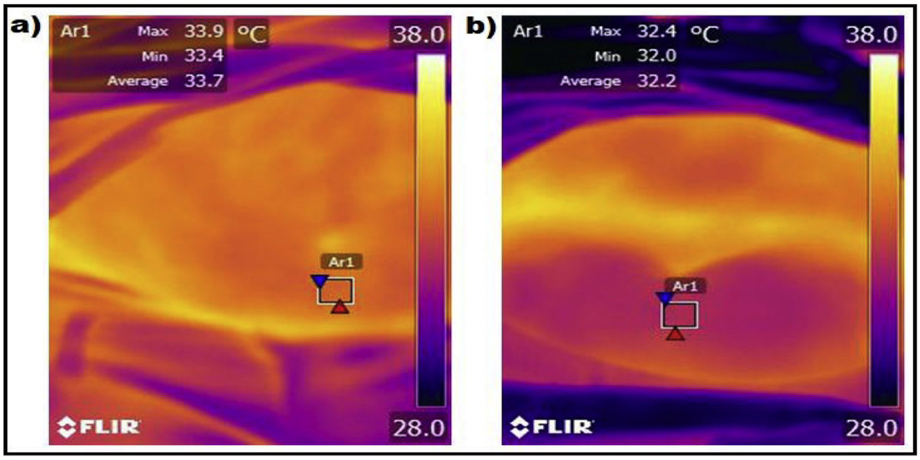

Fig. 3. An IRT image of abdomen region of a) a normal and (b) an obese subject. The abdomen skin temperature is higher in the lean subject as compared to the obese subject to maintain the normo-thermia condition.

fat tissue measured was found to be 1413.1 cm^3 (Steve et al., 2018). In the proposed study, similar separation of subcutaneous adipose tissue and visceral fat tissue was carried out. This measurement of the adipose tissue volume was obtained as 1955.11 cm^3 from the segmented MRI images of abdomen region.

Thermal imaging is also gaining importance in the field of assessment of fat in an individual. The relationship between BC and skin temperature can be used to estimate body fat percentage. Savastano et.al. promoted thermal imaging to examine the production and dissipation of heat in case of normal and an obese subject. They observed that the obese individual demonstrated significantly lower temperature in the abdominal region than in the normal subject. The temperature in finger bed region of a normal individual is significantly lower than that of an obese individual. The result obtained by Savastano et al. indicates the relatability of high body fat percentage (BF) % with skin surface temperature of the abdomen region (Savastano et al., 2009). This outcome explains that the difference in heat transfer through the abdominal skin of an obese individual is due to the presence of adipose tissue that acts as an insulating layer. Yosipovitch et al. proved that the abdomen, hip circumference and palm temperature were positively correlated with body fat percentage, whereas other regions of hands produced a negative correlation (T_{Mean} ($r = -0.430$), $T_{Minimum}$ ($r = -0.447$) and $T_{Maximum}$ ($r = -0.394$)) with the same (Yosipovitch et al., 2007). In the current study, similar results were obtained for the abdominal skin surface in obese and normal subjects. The average skin surface temperature measured at abdominal region for obese and normal subjects were found to be 32.2 ^{O}C and 33.7 ^{O}C respectively. The percentage difference in abdominal temperature between normal and obese subject was found to be 4.45%.

There are few shortcomings in the current study. There exists limited size of sample that has averted to get the generalized result. Some inter observer variability in ultrasound technology is noted due to the compression in tissue at the selected region of study. In MRI study, ectopic fat plays one of an important role in profiling BC. It helps to understand metabolic status and assessing risk. This study had not taken ectopic fat into consideration. Although it is a pilot study, the work shows that it is good stage to validate our findings with more on a larger set of data in different physical conditions and diseases related with obesity.

Future work will be involved in development and optimization of IRT image processing tools for brown adipose tissue (BAT) quantification in obesity assessment. Hence, there is a need for development of new user friendly devices with advanced software designed especially for the analysis of body composition in an individual.

The literature survey of various diagnostic techniques for assessing the obesity has been carried out and was tabulated in Table S3 (Kishore Mohan et al., 2010; Ballesteros-Pomar et al., 2012; Heuberger et al., 2012; Karlsson et al., 2013; JangSandyaJalapuMoe et al., 2014; Llewellyn et al., 2015; MunawarRiyadi et al., 2017; Vanderwall et al., 2017; Hartwig et al., 2017; Suganthi et al., 2017). In this survey, the methodology, key findings and sample size were discussed. These literature has predicted useful results from the modalities such as thermal imaging, BMI, BIA, CT etc.

In conclusion, non-invasive imaging methods have been used to observe the variations in body composition of lean and obese subjects. Ultrasound imaging method was one of the techniques used to determine the subcutaneous fat tissue and muscle thickness at thigh region in individuals. MRI imaging was used to obtain the subcutaneous fat tissue from the abdominal region. The thermal patterns in abdominal regions of lean and obese subject were analyzed and compared. Among the imaging modalities studied, thermal imaging and ultrasound technique was found to be feasible imaging modalities for the assessment of body composition in an individual.

Author contributions statement

The authors read and approved the final version of the manuscript, and agreed with the order of presentation.

Funding sources

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgments

We thank the participant for their valuable assistance with us in carrying out the protocols.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.obmed.2019.100150.

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