ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 03, pp.27939-27945, March, 2016

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

UNDERLYING PRINCIPLES AND THEORIES OF COMMON BODY COMPOSITION TECHNIQUES: A SYSTEMATIC REVIEW

***,[1]Ramananda Ningthoujam, [2]Takhellambam Inaobi Singh and [3]Bidhyapati Nongthombam**

[1]Senior Research Fellow, Department of Physical Education and Sports Science, Manipur University
[2]Associate Professor, Department of Physical Education and Sports Science, Manipur University
[3]Assistant Professor, Degree College of Physical Education, Amravati

ARTICLE INFO

Article History:
Received 20th December, 2015
Received in revised form
15th January, 2016
Accepted 08th February, 2016
Published online 16th March, 2016

Key words:

Body Composition,
Lean Body Mass,
Body Fat,
Multi-compartmental.

ABSTRACT

Context: The measurement of body composition helps in assessing nutritional status indirectly. It is considered to be an important factor in physical development especially in sports, where there is an advantage of being tall (e.g. basketball) or small (Libero, weightlifting), heavy (sumo wrestling, Shot Put) or light (gymnastics), etc.
Objective: To discuss the common methods of assessing human body composition for better understanding of the technique used.
Study Design: Systematic review
Evidence Acquisition: Relevant articles published from 1942 to 2012 obtained through searching MEDLINE, Google Scholar, Pub Med and SPORTDiscus™ and OVID with keywords body composition, human body composition, skinfold caliper, hydrostatic weighing, BOD POD, Tanita body composition analyser, bioelectrical impedance analysis, DEXA etc. Also, the body composition and body composition analyser websites were utilized.
Study Selection:
Five common methods for assessment of body composition were included for analysing the principles of the technique, advantages and disadvantages of the technique.
Data Extraction: Multi-Compartmental Model and densitometry technique were studied.
Results: DXA, Skinfolds, and Bio-impedance results have shown to be statistically different than Multi-Compartmental Model results and should not be compared to other technologies using the principles of densitometry such as Underwater Weighing and BOD POD.
Conclusion: Every technique has its advantages and disadvantages. A combination of these methods may reduce the likelihood of misdiagnosis of Body Composition.

Citation: Ramananda Ningthoujam, Takhellambam Inaobi Singh and Bidhyapati Nongthombam, 2016. "Underlying principles and theories of common body composition techniques: A systematic review", *International Journal of Current Research,* 8, (03), 27939-27945.

INTRODUCTION

Body composition is the amount of fat compared to lean body mass of our body and may be primarily referred to the distribution of muscle and fat in the body. A certain amount of body fat is necessary to be considered healthy for using it as an energy source during hard exercise. Being overweight is usually not a problem, but being over-fat typically has negative impact on the athletic performance. It is considered to be an important factor in physical development especially in sports, where there is an advantage of being tall (e.g. basketball) or small (Libero, weightlifting), heavy (sumo wrestling, Shot Put) or light (gymnastics), etc. Winter (1990), in his book on "Biomechanics and Human Movements" expressed that "Tall Runner's Longer Limbs will enable Longer Step Length". For a perfect physique, it is important to have a healthy amount of body fat: not too much and not too little. Body composition percentage varies considerably with gender, age, athletes and non-athletes. A study on world class sprinter by Niels Uth (2005), found that Height, Body Mass and BMI seems to be important anthropometric parameters for sprinters. The measurement of body composition helps in assessing nutritional status indirectly. The choice of body composition technique often depends on the intended purpose (for which data are to be used) and the available technology. In regard to high-performance sport, the assessment of body composition may define a performance or selection criterion, be used to assess the effectiveness of an exercise or dietary intervention,

Corresponding author: Ramananda Ningthoujam,
Senior Research Fellow, Department of Physical Education and Sports Science, Manipur University

or be used to monitor the health status of an athlete. Individual body composition goals should be identified by trained healthcare personnel (e.g. athletic trainer, physiologist, nutritionist or physician) and body composition data should be treated in the same manner as other personal and confidential medical information (Ackland *et al*., 2012). It is important to recognize that there is no single measurement method that allows for the measurement of all tissues and organs and no method is error free (Lee and Gallagher, 2008).

Common methods of assessing body composition

There are two techniques of measuring body composition i.e. Direct and Indirect measurement. A direct measurement of body composition is the most accurate method, it is not an option, as it requires dissection of the body. Direct technique of measuring body composition is also known cadaver analysis. It is a method of measuring body composition by dissecting a fresh, dead human body, and determining the percentage fat in each body part. On the other hand, indirect measurement used to determine body fat from body density which has been measured directly in previous cadaver analysis. Indirect method is also commonly said to be the best "reference" technique. Indirect methods such as BOD POD and Underwater Weighing have a small individual error. These methods are considered indirect because the equations used to determine body fat from body density are only one step from the direct method. Others indirect methods such as DXA, Skinfold Calipers, and Bio-impedance predict body fat by predicting density.

Multi-compartmental model

The most accurate assessment of our ideal weight takes into account the composition of our body i.e. defining how much of our weight is lean body mass (muscle and bone) and how much is body fat. The closest researchers can get to a direct measurement of body composition as far as accuracy goes is by using the Multi–Compartment Model technique. The Multi-Compartment Model used to measure body composition requires a combination of measurement methods. It can determine Total Body Water, Body mass, Body Volume by air displacement (BOD POD) or Underwater Weighing (UWW), Bone Mineral Content by Dual-Energy X-Ray Absorptiometry (DXA) and nutritional-importance information.

DXA (Dual Energy X-ray Absorptiometry)

Principles

DXA (previously DEXA) was developed by Mazess *et al.* (1990) for bone mineral content and density measurement. The DXA (Figure 1) technique involves a small amount of radiation, and is usually administered by a department qualified to use radiation for medical imaging. Two x-ray beams with differing energy levels are aimed at the patient's bones. When soft tissue absorption is subtracted out, the BMD can be determined from the absorption of each beam by bone.

Advantages

Today, this method is considered a gold standard method in children, (Goran *et al*.,1996) young man and women (Mezess *et al*., 1993) because of its reliability, precision, and the fact that it is based on three body components (fat, muscle, bone) rather than two (fat and muscle) as in most other methods including hydrostatic weighing.

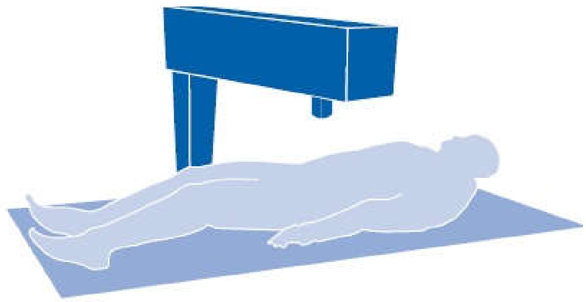

Figure 1. Dual Energy X-ray Absorptiometry

DXA is most widely used modality for the clinical measurement of bone mineral content (Compston *et al*, 1995). Lukaski (1993) reported 99% accuracy in measurement of bone mineral content and density with only 1% error. The major advantages of this technique is, it takes short time (<10 mins) for measurement, precision is quite good (1-2 % variance), and dose of radiation is minimal (< 0.01 mSv, whole body) (Goran *et al*., 1996; Mazess *et al*., 1990). It allows fat distribution throughout the entire body to be read in a single scan. Literature suggests that DEXA can be used to detect small changes in bone mineral content at multiple anatomical sites, with little exposure to radiation, short examinations time, high resolution images (Mazess *et al*.,1993), and excellent precision (0.5 -> 2%) and accuracy (3->5%) (Sorenson *et al*., 1998). DXA is not effected by ethnicity, athletic status or musculoskeletal development (Aloia *et al*., 1999; Prior *et al*., 1997).

Disadvantages

The equipment used is very expensive and a person must lie perfectly still for 10-20 minutes while the scan is taken. Any movement during DXA whole body scan will lead to invalid test results. In a recent study (William *et al*., 2006) the accuracy of DXA (Lunar Prodigy) was compared with 4-CM and found that the inconsistent bias of DXA varies according to sex, size, fatness and disease status, indicating that DXA is unreliable for patient case-control studies and for nutrition/health longitudinal studies. Lunar DXA was found significantly underestimated %BF by ~ 4 %fat respect to other three different methods (UWW, TBW AND TBK) in a sample of 12 endurance athletes (Withers RT *et al*., 1992). Some literature suggested that DXA is of limited use in people with a spinal deformity or those who have had previous spinal surgery.

Underwater Weighing

Principles

Underwater weighing (UWW) measurement is based on Archimedes' Principle that states "when a body is immersed in a fluid, body volume is equal to the loss of weight in the water" (Figure 2). This technique typically requires the subject to be completely submerged underwater while exhaling maximally to minimize the effect of buoyancy from lung air.

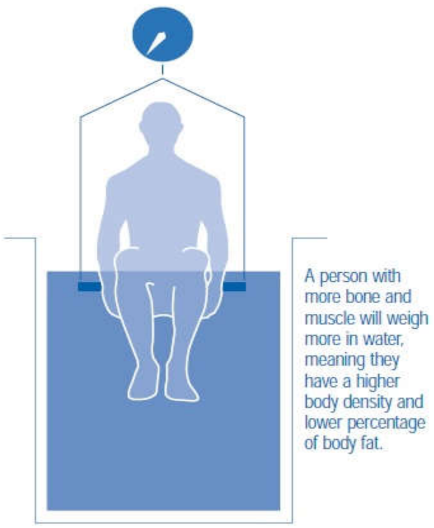

Figure 2. Underwater Weighing

It estimates body composition from body density (D = Mass/Volume). The mass is measured on a scale on land. The subject must exhale all air as head is lowered under water. Residual Volume (RV) must be measured to obtain most accurate results. Computing Db to %BF - Established equations are used that incorporate measured densities of fat and fat-free mass, such as:

Density of fat = 0.9007 g * cm-3 …..… (1)

Density of fat-free = 1.100 g * cm-3 ……..(2)

Denser the body is, the lower is the percentage of body fat and the less denser a body is, the higher is the body fat. The most accurate method for measuring RV is to obtain the measurement at the same time the subject is submerged in the tank, while their body volume is being measured, as opposed to measuring RV when the subject is outside the tank. Residual Volume (RV) is then subtracted from the Total Body Volume measurement. Hydro-densitometry is considered to be the gold standard of the densitometric methods.

Advantages

Based on considerations of expense and the precision and accuracy of measurement, the underwater weighing technique continues to be the most widespread and useful method for estimating body volume leading to the assessment of body composition (Going, 1994). Hydrodensiometry is an established reference method for measuring body density (Fuller, 1992).

Disadvantages

The limitations associated with this method include time, labor intensity, subject discomfort and inaccessibility for many special populations such as the elderly, disabled, and chronically ill (Biaggi *et al.*,1999; Jebb and Elia, 1993; Behnke *et al.*,1942).Willmore (1969) hydrostatic weighting, using predicted residual lung volume had no effect on the estimation of %BF for the group. However, individual estimates deviated quite substantially from that calculated by using measured residual lung volume, with over 50% of the subjects having deviations in density values ranging from ±0.003 to greater than ±0.0099 g/ml (%BF deviations ranging from 1 to 4%). Ball SD. (2005) there is a wide range of equipment and protocols commonly used in laboratories measuring underwater weight (autopsy scale vs. load cells), subject position, calibration, and method for determining residual lung volume (simultaneous vs. separate, underwater vs. land, helium vs. oxygen dilution). Of these, differences in residual volume determination and trial selection criteria have been reported to contribute the largest sources of variation. Moreover, the test is somewhat subjective because it relies upon the subject's ability to expel all oxygen from their lungs while submerged in a water tank. Oxygen remaining in the lungs will skew the results. In clinical settings, this procedure is repeated a number of times, and an average is taken. The "tank" is expensive and the inconvenience to the user is considerable. Because of the cost, lengthy testing process, and physical burden to the subject, this method is more suitable for research studies

Figure 3. Bioelectrical Impedance Analysis

Bioelectrical impedance analysis

Principle

Bio-impedance devices (Figure 3) that pass a small, alternating electric current (I) 800 µA, Frequency; 50 kHz through the body, and the resistance (Body fat, cell membranes) to that current indicates the amount of water in the body. The current passes between two electrodes, often called the source and sink (or detector), and generates voltages between different points in the body volume according to Ohm's law. Larger the fat–free mass, lesser is the resistance to current and larger fat mass, more resistance to current. The currentflows through all conducting materials present in the body in the path between the source and sink electrodes. Because living tissue constitutes a volume conductor, the physical carriers of the current are predominantly charged ions, such as sodium (Na^{++}) or potassium (K^{+}) ions, which are able to move within the volume. Conductivity within materials such as blood and urine is high, that of muscle is intermediate, and that of bone, fat, or air is low. The actual parameter measured with Bio-impedance Analysis (BIA) is the voltage (V) that is produced between two electrodes located most often at sites near to, but different from, the sites where current is introduced. The measurement normally is expressed as a ratio, V/I, and is also called impedance (Z). The measuring instrument is therefore called a bioelectrical impedance analyzer.

Advantages

The equipment is not expensive, making a professionally-accepted method that can be adapted easily for home use. There is no physical imposition to the user; no need for a trained technician to operate the equipment; and the entire procedure takes less than one minute. Lukaski *et al*.(1985) reported in their study that bio-impedance analysis method is a valid and reliable approach for the estimation of human body composition. They found a reliability coefficient of 0.99 over 5 days.

Disadvantages

Although BIA is an attractive assessment tool and easy to use, it should be recommended as an alternate to the skin-fold method only when trained skin-fold technician are not available (Utter C. Allan 2005). Body position, posture, serum electrolytes, blood flow, skin temperature, fluid distribution, and vascular perfusion all can significantly change the observed resistance (Pinilla *et al*., 1992; Caton *et al*., 1988; Kushner *et al*., 1996)

Skinfold Calipers

Principle

Skinfold Caliper (Figure 4) is to determine the subcutaneous fat whether it is increasing or decreasing, but not for predicting total body fat. A small, hand-held device called Skinfold Caliper is used to measure the thickness of fat immediately below the skin's surface, which is also called subcutaneous fat. Usually 3 to 12 locations are chosen to measure. The most common sites are: suprailiac, anterior thigh, triceps, and subscapular. Once fat-folds are measured they are put into one of hundreds of different population-specific or generalized equations to determine BF%.

Figure 4. Skinfold caliper

Jackson and Pollock (1978) formulate an equation that has been validated for various age groups and both athletic and non-athletic populations from the three sites of skinfold measurement. These equations are:

Men: $D=1.1125025-0.0013125(x) + 0.0000055(x^2) - 0.000244(y)$ ………………..(3)

Women: $D=1.089733-0.0009245(x) + 0.0000025(x^2) - 0.0000979(y)$ ………………..(4)

Where x=sum of triceps, chest, and subscapular skinfolds (in mm) for men, and the sum of triceps, suprailiac, and abdominal skinfolds for women, and y =age in years.

Advantages

Skin-fold measurements taken by calipers are easy to use, inexpensive, and the method is portable. However, results can be very subjective depending on the skill of the technician and the site(s) measured. Inexpensive models sold for home use are usually less accurate than those used by an accredited technician. Many people find calipers to be uncomfortable and invasive but it is most commonly used in the field of sports for testing body fat.

Disadvantages

These 3 to 12 local fat measurements are used to predict the overall fat content of the entire body, however, significant errors can result from this approach, because people deposit fat in different areas, and about half of the fat content of the body is internal, which skinfold caliper cannot measure. Because of this, the accuracy of skinfolds on an individual basis is not very high, with research studies indicating errors of up to ±8% (Scherf *et al*., 1986). Example: If someone is really 20% fat, Skinfold Calipers could measure the person between 12 and 28% fat.

Table 1. Advantages and disadvantages body composition techniques

Method	Primary measurement	Advantages	Disadvantage
DXA	TBF, LM, bone mineral	Measure entire body fat	Needs expert to operate, takes10-20 minutes
Skinfold	Visceral fat	Easy to use, inexpensive, portable	Needs an expert to measure accurately
Underwater Weighing	Body density	Gold standard method in fat % measurement	Subject discomfort, limited to ill person
BIA	TBW, fat mass, fat %	Inexpensive, portable, simple, easy to use	Accuracy affected by exercise, diuretics, etc
BOP POD	Body volume, body weight	Reliable and requires minimal expertise	Expensive, accuracy reduces to sick person

DXA, dual energy X-ray absorptiometry; TBF, total body fat; LM, lean mass; TBW, total body water

The error in body fat estimates from Skinfold ranges from ± 3% to ± 11 %, and is influenced by sex, ethnicity, age and measurement sites (Wang *et al*., 2000). There is little research comparing Skinfold percent fat measurements and Multi-Compartmental Model measurements because the principles and assumptions are completely different. For this reason, Skinfold measurement should also not be compared to methods such as Underwater Weighing and BOD POD.

The BOD POD

Principle

The BOD POD (Figure 5) is an Air Displacement Plethysmograph (ADP) that uses whole-body densitometry to determine body composition (fat vs. lean). It is similar in principle to the underwater weighing; body density measured with the BOD POD was higher than the criterion Hydrostatic Weighing, thus yielding lower %fat scores for the BOD POD. Thoracic Gas Volume (TGV) is accounted for instead of RV. In addition, BOD POD determined %fat was lower than DXA and 3C determined values. The BOD POD measures body mass (weight) using a very precise scale, and volume by sitting inside the BOD POD. Body density can then be calculated:

Density = Mass/Volume …………(5)

If the body density is known, it is possible to convert this to a body fat % using the following equation, which was derived by Siri:

% fat= (495/body density)-450 ………….(6)

The BOD POD body composition system uses the relationship between pressure and volume to derive the body volume of a subject seated inside a fibre-glass chamber. Derivation of body volume, together with measurement of body mass, permits calculation of body density and subsequent estimation of percent fat and fat-free mass. The density of the whole body (mass per unit volume) may be used to estimate human body composition. Once the overall density of the body is known, the relative percentages of fat and fat-free mass may be determined by an equation such as the one derived by Siri`s equation as shown in equation (6) above. The more denser a body is, the lower is the percentage of body fat; the less denser a body is, the higher is the body fat.

Advantages

Assessment of fat% using the BOD POD is reliable and requires minimal technical expertise (Collins *et al*., 1999). BOD POD is the only technique that can estimate fat mass accurately, precisely, and without any bias in 9 to 14 yr-old children (Fields *et al*., 2000). The average of the study means indicates that the BOD POD and underwater weighing agree within 1%BF for adults and children (Field *et al*., 2002).

Disadvantages

BOD POD is very expensive and its accuracy reduces if used in diseased states. BOD POD test protocol will also insure the accuracy and precision of the measurement, so it is important to be relaxed, still, and avoid talking or coughing during the test. The device lacks portability, requiring a small space in the room.

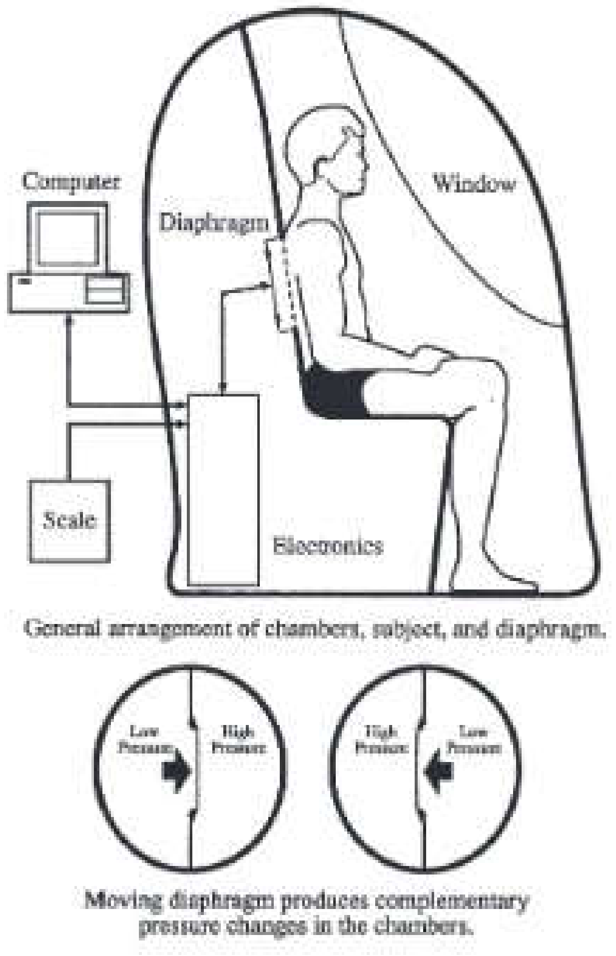

Figure 5. The BOD POD

Others Technique

There are other techniques that are not cover in this articles i.e., nitrogen, oxygen, or helium dilution or nitrogen washout technique, isotope dilution, near-infraredinteractance (NIR) deuterium or 180 labeled water dilution, Three-dimensional photonic scanner. Hence, they are also used in different fields for analyzing human body composition.

Summary

Every technique has there advantages and disadvantages (Table 1). A combination of these methods may reduce the likelihood of misdiagnosis of Body Composition. DXA, Skinfolds, and Bio-impedance results have shown to be statistically different than Multi-Compartmental Model results and should not be compared to other technologies using the principles of densitometry such as Underwater Weighing and BOD POD because the principles and assumptions are completely different.

Conflict of Interest: None

REFERENCES

Allan CU, David CN, Gregory JM, Richard T, Sean S, Tim M, James RM. 2005. Evaluation of leg-to leg BIA in assessing body composition of high school wrestler. *Medicine & Science in Sports & Exercise,* d.o.i: 10.1249/01.mss. 0000174901.05353.f2.

Aloia JF, Vaswani A, Mikhail M, Flaster ER. 1999. Body Composition by dual-energy x-ray absorptiometry in black compared with white females. *Osteoporisis International,* 10: 114-119.

Ball SD. 2005. Interdevice variability in percent fat estimates using the BOD POD. *Eur J Clin Nutr*., 59:996-1001.

Behnke AR, Feen BG, Welham WC. 1942. Specific gravity of healthy man. *JAMA*, 118:496-501.

Biaggi RR, Vollman MW, Nies MA. 1999. Comparison of air displacement plethysmography with hydrostatic weighing and bioelectrical impedance analysis for the assessment of body composition in healthy adults. *Am J Clin Nutr.,* 69:898-903

Bioelectrical impedance analysis in body composition measurement. *National institute of health technology assessment conference statement* 1994; Dec 12 – 14.

Brodie, DA. 1988. Techniques of measurement of body composition Part II. *Sports Medicine*, 5: 74-98.

Caton JR, Mole PA, Adams WC, Heustis DS. 1988. Body composition analysis by bioelectrical impedance: effect of skin temperature. *Med Sci Sports Exerc*, 20:489-491.

Collins MA, Millard-Stafford ML, Sparling PB, Snow TK, Rosskopf LB, Webb SA, Omer J. 1999. Evaluation of the BOD POD for assessing body fat in collegiate football players. *Medicine and Science in Sports and Exercise*, 31(9):1350-1356. PMID:10487380. d.o.i: 10.1097/0000 5768-199909000-00019.

Edward LF, Richard WB, Merle LF. *The Physiology basis of physical education and athletics (4th Edition).* pp 553- 572.

Fields DA, Goran MI, McCrory MA. 2002. Body-composition assessment via air-displacement plethysmography in adults and children: a review. *Am J Clin Nutr*., 75:453-467.

Fields DA, Goran MI. 2000. Body composition techniques and the four-compartment model in children. *J Appl Physiol.,* 89:613-620.

Fuller NJ, Jebb SA, Laskey MA, Coward WA, Elia M. 1992. Four-component model for the assessment of body composition in humans: comparison with alternative methods, and evaluation of the density and hydration of fat-free mass. *Clin Sci*., 82: 687-693.

Going SB. Densitometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. 1996. Human Body Composition. Champaign, IL: *Human Kinetics*, 3-24.

Goran MI, Driscoll P, Johnson R, Nagy TR, Gary H. 1996. Cross-calibration of body composition techniques against dual-energy x- ray absorptiometry in young children. *American Journal of Clinical Nutrition*, 63: 299-305.

http://www.biodyncorp.com/product/450/body_model_450.html.

http://www.bodpod.com/en/products/body-composition/adult-children-bod-pod-gs/bod-pod.

http://www.brianmac.co.uk/fatcent.htm.

http://www.calculator.net/lean-body-mass-calculator.html.

http://www.tanita.com/en/body-composition-analyzer/.

http://www.topendsports.com/testing/bodycomp.htm/.

Ionescu EO, Gurău AI. The importance of body composition measurement at athletes and non-athletes. *Sport Medicine Journal* 2006; No.6.

Jackson AS. and Pollock ML. 1978. Generalized equations for predicting body density of men.*Br J Nutr.* Nov; 40(3):497-504.

Jebb S, Elia M. 1993. Techniques for the measurement of body composition: a practical guide. *Int J Obes Relat Metab Disord*., 12:57-65.

Kushner RF, Gudivaka R, Schoeller DA. 1996. Clinical characteristics influencing bioelectrical impedance analysis measurements. *Am J Clin Nutr*., 64:423S-427S.

Lukaski H.C. 1993. Soft tissue composition and bone mineral status: Evaluation by dual energy x ray absorptiometry. Symposium: Aging and body composition: Technological advances and physiological interrelationships. *Journal of Nutrition,* 123:438-443.

Lukaski, H. C. 2009. Evaluation of body composition: why and how? *Mediterranean Journal of Nutrition and Metabolism*, 2(1): 1-10. doi: 10.1007/s12349-009-0042-x.

Lukaski, H.C., Phyllis, E. J., William W. B., Glen I L. 1985. Assessment of fat-free mass using bioimpedance measurements of the human body. *Am J Clin Nutr*., 41: pp 810-817.

MACKENZIE, B. 2015. Body fat Percentage 1998; (WWW) Available from: http://www.brianmac.co.uk/fatcent.htm (Accessed 7/2/2015).

Marie Dunford. Sports Nutrition: A Practice Manual for Professionals. In: Christopher M M. Assessment of body size and composition 2006; pp:177-210.https://books.google.co.in/books?isbn=0880914114

Mazess, R.B., Burden, H.S., Bisek, J.P.and Hanson, J. 1990. Dual-energy x-ray absoptionmetry for total-body and regional bone-mineral and soft tissue composition. *American Journal of Clinical Nutrition*, 51: 1106-1112.

McArdle, W. D., Katch, F. I. & Katch, V. I. 2001. *Body composition assessment. Exercise physiology: Energy,* *Nutrition and Human Performance (5th Edition)*, Pp 752-931.

Michael Chia and Jasson Chiang. Sport, Science, and Studies in Asia: Issues, Reflections, and Emergent Solutions. Proceedings of the 2008 ACESS Conference in Sports Science. World Scientific Publishing Co. Pte. Ltd. 2010.

Niels U. 2005. Anthropometric Comparison of World-Class Sprinters and Normal Populations, *Journal of Sports Science and Medicine,*4: 608-616.

Philip D. and Susan A. 1995. A new air displacement method for the determination of human body composition. *Medicine and Science in Sports Exercise*, June; 1692-1697.

Pinilla JC, Webster B, Baetz M, Reeder B, Hattori S, Liu L. 1992. Effect of body position and splints in bioelectrical impedance analysis. *J Parenter Enteral Nutr*., 16:408-412.

Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger MA, Saunders M. 1993. In vivo validation of whole body composition estimates from dual-energy x-ray absorptiometry. *Journal of Clinical Nutrition*, 47(3): 216-28.

Scherf J, Frankli BA, Lucas CP. 1986. Validity of skinfold thicknesses in formally obese adults. *Am J Clin Nutr*., 43:128-135.

Seon Yeong Lee, 2008. Dympna Gallagher.Assessment methods in human body composition. *Curr Opin Clin Nutr Metab Care*, 11(5): 566–572.doi: 10.1097/MCO. 0b013e32830b5f23

Siri WE. 1961. Body composition from fluid space and density. In J. Brozek & A. Hanschel (Eds.), Techniques for measuring body composition. Washington, DC: *National Academy of Science*, 223-244.

Timothy R. Ackland, Timothy G. Lohman, Jorunn Sundgot-Borgen, Ronald J. Maughan, Nanna L. Meyer, Arthur D. Stewart and Wolfran Miiller. 2012. Current status of body composition assessment in sport. *Sports Med*., 42(3): 227-249.

Wang J, Thornron JC, Kolesnick S, Pierson RJ. 2000. Anthropometry in body composition. *Ann N Y Acad Sci*., 904.

Williams JE, Wells JC, Wilson CM, Haroun D, Lucas A, Fewtrell MS. 2006. Evaluation of Lunar Prodigy dual-energy X-ray absorptiometry for assessing body composition in healthy persons and patients by comparison with the criterion 4-compartment model. *Am J Clin Nutr*., 83:1047-1054.

Wilmore JH. 1969. The use of actual, predicted and constant residual volumes in the assessment of body composition by underwater weighing. *Med Sci Sports Exerc*., 1:87-90.

Winter D.A. 1990. Biomechanics and motor control of human movement. 2nd Edition New York: Wiley-Inter science 51-74.

Withers RT, Smith DA, Chatterton BE, Schultz CG, Gaffney RD. 1992. A comparison of four methods of estimating the body composition of male endurance athletes. *Eur J Clin Nutr*., 46:773-784.

****