# A NEW APPROACH FOR ESTIMATION OF BODY MASS INDEX USING WAIST AND HIP CIRCUMFERENCE IN TYPE 2 DIABETES PATIENTS

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**Background:** Body mass index (BMI), derived by dividing weight (Kg) by the square of height (m), is a useful anthropometric parameter, with multiple applications. It is dependent upon accurate measurement of its component parameters. Where measurement of height and weight with calibrated instruments is not possible, other objective parameters are required to maintain accuracy. **Objectives:** We aimed to propose an alternate prediction model for the estimation of BMI based on statistical linear regression equation using hip and waist circumferences. Our objective was to ascertain the accuracy of estimated BMI when compared with observed BMI of patients, and to propose a model for BMI prediction which would overcome problems encountered in the prediction of body mass index of critically ill or immobile patients, needed for applications such as BMI based calculations in ventilation protocols in ICUs. **Methods:** This cross sectional survey was done by reviewing hospital records of adult subjects of both genders (n=24,485; 10,687 males and 13,798 females), aged 20 years and above, who were diagnosed with type 2 diabetes. Two different prediction models were designed for males and females keeping morphological and physiological differences in gender. The measured waist and hip circumference values were used to estimate BMI. **Results:** Data analysis revealed a significant linear relationship between BMI, waist and hip circumference in all categories [waist circumference (r=0.795, $p$=0.000), hip circumference (r=0.838, $p$=0.000)]. Estimated regression models for males and females were BMI= -10.71+0.212(hip cir)+0.170 (waist circumference); and BMI= -15.168+0.143 (hip circumference)+0.30 (waist circumference) respectively. **Conclusion:** Estimation of BMI using this prediction model based upon measured waist and hip circumferences, is an alternate and reliable method for the calculation of BMI.

**Keywords:** Body mass index, BMI, waist circumference, hip circumference, Multiple Linear Regression model, Correlation, Diabetes mellitus

## INTRODUCTION

Obesity has been linked with many of the leading causes of death in the developed world, including diabetes mellitus, ischemic heart disease and cancer.[1] Conventional parameters used to define obesity include Body Mass Index (BMI) and waist circumference (WC). Population based surveys including cross-sectional[2,3] and prospective studies [4–7] have shown that BMI and waist circumference are useful parameters in predicting cardiovascular risk. In particular, a high WC is a significant predictor of visceral obesity, which has been shown to be associated with atherosclerotic process and the metabolic syndrome.[8]

Traditionally, BMI has been used to stratify individuals into normal weight, under weight or obese, with risk of metabolic diseases increasing at either end of the spectrum. According to the system of classification used by National Institutes of Health, accepted normal BMI (Kg/m$^2$) range for men and women is from 18.5 to 24.9.[9] Values beyond this range are considered to be predictors of greater relative health risk. This pattern of increasing morbidity at extremes of BMI has been called a J-shaped curve[10], in recognition of the fact that there is no direct or linear relationship between BMI and morbidity. The disadvantage of using BMI in such risk models lies in the fact that it does not differentiate between lean body mass and fat mass. Body fat can be measured by different techniques for analysis of body composition such as whole body immersion or bioelectrical impedance, both of which require specialized equipment and trained personnel. In contrast waist circumference is a simple, non-invasive test which requires minimal equipment and observer training.[9] Waist circumference has been shown to correlate with abdominal obesity, which is associated with insulin resistance and the metabolic syndrome.[10] Measuring waist circumference as part of CV risk stratification of an individual is convenient, sensitive and cost effective.

While the World Health Organization (WHO) has published standards for overweight and obesity in adult populations based on BMI (kg/ m$^2$)[11] and has categorized BMI for identifying health risk, it has been shown that excess abdominal fat distribution contributes additional risk for cardiovascular disease beyond the effect of BMI alone.[12]

Direct measurement of abdominal obesity is only possible by difficult procedures such as CT based methods, in conjunction with special software designed for this purpose. Surrogate methods for measuring abdominal obesity include BMI and waist circumference. Anthropometric research indicates that waist circumference (WC) is a superior to both body mass index (BMI) or waist-to-hip ratio (WHR) as an indicator of abdominal obesity.[13–17] Furthermore, WC is a major component of most definitions of the metabolic syndrome: WC cut-offs for Caucasian men and women with the metabolic syndrome have been set at >88 cm in females and >102 cm in males in the IDF definition.

Information regarding height and weight of the patients is essential for daily clinical practice, especially in intensive care units (ICUs), where many critical parameters depend upon accurate measurement of weight. Measuring height and weight in critically ill ICU patients is often extremely difficult, necessitating the use of special beds and weighing apparatus.[18] In usual ICU practice, the patients' body weight is estimated by the nurses or doctors, resulting in inaccuracy in those calculations which require a correct weight or BMI, such as allocation of ventilator protocols.[19]

Estimates of height and weight are subject to considerable inter-observer variation, which may be clinically significant.[20] These errors in estimation can compromise clinical management such as drug dose calculation, and adversely affect the conduct of clinical research trials.[21] Objective measurements with calibrated instruments are necessary for accuracy in clinical practice and research trials, as well as for patients' safety.[22]

Our aim was to ascertain the accuracy of estimated BMI when compared with observed BMI of patients, and to overcome problems in the prediction of body height and weight of patients in the ICU, or on life support equipment. By using this model, calculation of Body mass index (BMI) can be done easily using a simple formula based upon measured waist circumference.

## SUBJECTS AND METHODS

This cross sectional survey was carried out in Diabetes Management Centre (DMC) Services Hospital Lahore. The hospital record of adult subjects who were diagnosed as type-2 diabetes and were treated in DMC on out-patient basis was evaluated. The patients (n=24,485, 10,687 males and 13,798 females) were aged 20 years and above, and belonged to both rural and urban areas of Punjab province.

During their clinic visit, the patients underwent preliminary physical examination including measurement of weight on a calibrated analog scale, and height using a digital stadiometer (Seca 242, USA). These parameters were used to calculate the BMI, using the formula: weight (Kg)/height ($m^2$). Waist was measured at the level of the anterior superior iliac spine, while hip circumference was measured at the level of maximum protuberance of the buttocks. Inter-observer variability was minimised through instructional videos and supervised training sessions. This information was stored digitally in Hospital Information Management System (HIMS) and was used for comparison on subsequent visits of the patients.

We designed a statistical linear regression model for the estimation of BMI using waist and hip circumferences and used the hospital data for waist and hip circumferences and to compare the values obtained from this model with calculated BMI values by measured weight and height.

Two different prediction models were designed for males and females keeping morphological and physiological differences in gender. The measured waist and hip circumference values were used from the hospital data to estimate BMI.

Data was analysed using SPSS-12.0 descriptively and analytically. In descriptive analysis, Mean±SD were calculated for quantitative variables like patients' age, height, weight, BMI, waist circumference and hip circumference etc., while count and percentages were calculated for qualitative variables.

In analytical section, multiple linear regression analysis was applied to establish a linear relationship between BMI, waist circumference and hip circumference taking BMI as dependent variable. Matrix Plot was use to assess the linear relationship between dependent and independent variables graphically. Variance inflation factor (VIF) used to check the assumption of multicolinearity among the predictors. Assumption of normality of errors was check by P-P plots. Adjusted $R^2$ was used to check the adequacy of the fitted model. Moreover partial correlation analysis was made to find the correlation between BMI, Waist circumference and hip size controlling for age. Statistical significance was defined at the 5% level.

## RESULTS

Table-1 shows that out of 24,485 subjects, 10,687 (43.65%) were males and 13,798 (56.35%) were females. Mean±SD comparison for anthropometric characteristics was constructed for overall, male and female populations. The average BMI of females was significantly higher than male patients ($p<0.05$).

These Matrix plot indicate a linear relationship between BMI and predictors (waist & hip measurement) both in males and females as well (Figure-1). Assumption of multicollinearity was checked by Variance inflation factor (VIF) and found that there was no multicollinearity between predictors as value of VIF<10. For the assumption of normality of errors was checked by P-P plots and found that standardised errors were normally distributed (Figure-2). Adjusted $R^2$ explains that how much variation can be explained in the dependent variable by the predictors.[23] Value of Adjusted $R^2$ for males fitted model was about 76.0% while for females 80.0%

All outlying values (leverage and influential) have been removed before fitting the final regression model. Table-3 gives the out of regression.

According to the WHO defined BMI categories, a majority of our sample consisted of overweight and obese individuals, who are at risk for development of the metabolic syndrome. (Table-2)

There was a significant linear relationship between BMI; waist and hip circumference in all categories [waist circumference (r=0.795, *p*=0.000), hip circumference (r=0.838, *p*=0.000)].

Table-4 shows comparison of observed BMI with estimated BMI. By comparison, it was found that there was no significant change in the category of BMI by either method. Thus our results support the assumption that BMI can be estimated with prediction model reliably using hip and waist circumferences.

The proposed linear regression models for estimating BMI we designed and used for males and female subjects were as follows:

**For males:**

BMI= -10.71 + 0.212 (hip circumference) +0.170 (waist circumference)

**For females:**

BMI= -15.168+0.143 (hip circumference)+0.30 (waist circumference)

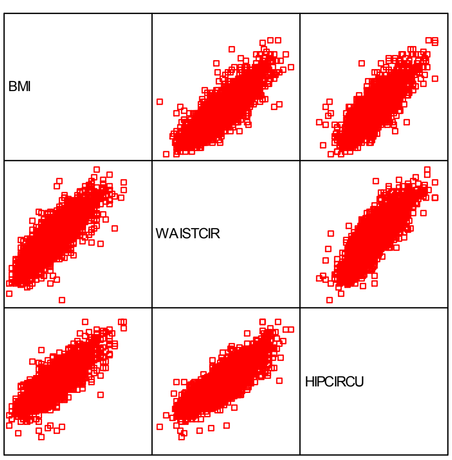
**Table-1: Descriptive analysis for Anthropometric Characteristics**

| Population | n | AGE (Years) | Weight (Kg) | Height (Cm) | BMI (Kg/m$^2$) | Waist (Cm) | Hip (Cm) |
|---|---|---|---|---|---|---|---|
| **Overall** | 24485 | 50.16±10.828 | 70.14±14.229 | 159.59±9.158 | 27.54±5.212 | 95.82±11.854 | 99.09±10.499 |
| **Male** | 10687 | 50.77±11.304 | 73.41±14.167 | 167.34±6.571 | 26.16±4.569 | 95.70±11.837 | 97.81±9.499 |
| **Female** | 13798 | 49.68±10.421 | 67.61±13.729 | 153.60±5.749 | 30.61±5.423 | 95.87±12.057 | 100.03±11.419 |

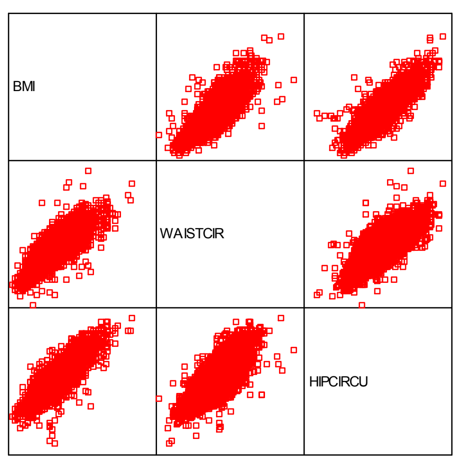
**Table-2: Categories of BMI to identify, health risk**

| BMI | Weight categories | Risk | Male % | Female % |
|---|---|---|---|---|
| **<18.5** | Underweight | No Risk | 384 (3.6%) | 221 (1.6%) |
| **18.5–24.9** | Normal Weight | Least Risk | 3550 (33.2%) | 2845 (20.6%) |
| **25–29.9** | Overweight | Increased Risk | 4575 (42.8%) | 5230 (37.9%) |
| **30 and Over** | **Obese** | | | |
| **30–34.9** | Obese Class I | High Risk | 1717 (16.1%) | 3659 (26.5%) |
| **35–39.9** | Obese Class II | Very High Risk | 360 (3.4%) | 1359 (9.8%) |
| **>40** | Obese Class III | Extremely High Risk | 101 (0.9%) | 484 (3.5%) |

(Source: WHO guidelines for body weight classification in adults 2003)




**Male**




**Female**

**Figure-1: Showing a linear relationship between Dependent and predictors for Males & Females**

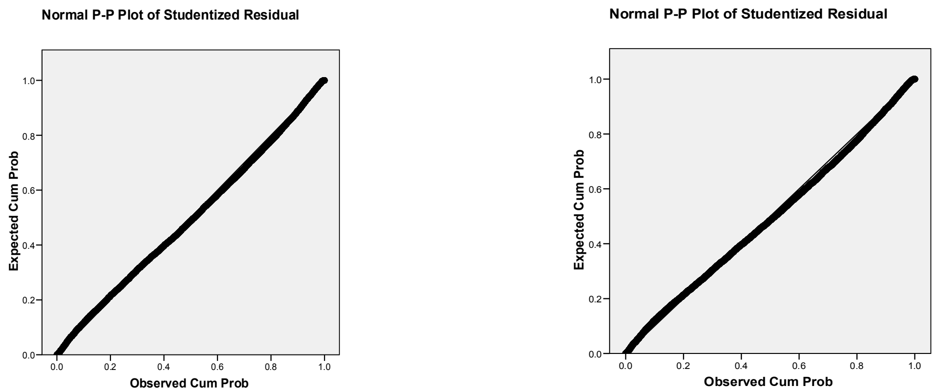



**Figure-2: Checking of Normality assumption by P-P plot in Male/Female Models, respectively**

**Table-3: Estimated Regression Coefficients**

| Variable | MALE | | | Female | | |
|---|---|---|---|---|---|---|
| | β | SE | *p* | β | SE | *p* |
| Constant | -10.71 | 0.229 | 0.000 | -15.168 | 0.202 | 0.000 |
| Waist Circ. | 0.211 | 0.003 | 0.000 | 0.143 | 0.003 | 0.000 |
| Hip Circ. | 0.17 | 0.004 | 0.000 | 0.3 | 0.003 | 0.000 |

**Table-4: Comparison of Observed & Estimated BMI**

| Observed BMI | Waist (cm) | Hip (cm) | Estimated BMI |
|---|---|---|---|
| MALE | | | |
| 40 | 108 | 124 | 37.476 |
| 32 | 99 | 115 | 33.489 |
| 24 | 86 | 91 | 24.43 |
| 31 | 102 | 108 | 31.818 |
| 34 | 101 | 123 | 36.175 |
| 29 | 101 | 106 | 31.075 |
| 25 | 89 | 101 | 27.859 |
| 25 | 93 | 95 | 26.631 |
| 37 | 129 | 108 | 35.679 |
| 31 | 98 | 109 | 31.546 |
| 40 | 108 | 124 | 37.476 |
| FEMALE | | | |
| 37 | 121 | 109 | 33.13 |
| 31 | 109 | 106 | 30.235 |
| 26 | 93 | 100 | 26.013 |
| 23 | 80 | 85 | 20.75 |
| 25 | 98 | 102 | 27.355 |
| 25 | 93 | 88 | 23.841 |
| 27 | 96 | 94 | 25.515 |
| 32 | 117 | 107 | 31.984 |
| 24 | 83 | 90 | 22.243 |
| 27 | 101 | 97 | 27.038 |
| 37 | 121 | 109 | 33.13 |

## DISCUSSION

Estimation of height and weight, and by derivation, BMI, is required in settings where direct measurement of these parameters is not possible. This problem may arise due to non-availability of equipment, particularly when weighing the patient requires specialised equipment, such as bariatric, wheel chair or bed scales. This situation is frequently encountered in the critical care setting, where weighing immobile or ventilated patients is required for a variety of reasons, such as determination of drug dose or infusion flow rates, and calculating ventilation parameters. In the absence of objective measurements of height and weight, ICU staff use estimates of these parameters based upon observation and clinical experience. A survey of intensive care units in England confirmed that patient weight is often estimated by experienced ICU nurses, although these estimates showed significant inaccuracy.[20]

The inaccuracy of these estimates was also shown in a recent study conducted in Department of Intensive Care, Aberdeen Royal Infirmary, Aberdeen, UK to ascertain the accuracy of estimates of weight and height of patients made by intensive care unit (ICU) staff. Patients were weighed using hoists attached to calibrated weighing apparatus, while an inelastic steel tape measure was used to measure height. It was seen that estimation of weight was fairly inaccurate, with 47% and 19% of estimates differing by 10% and 20% respectively, from the measured values.[21] On the other hand, weighing the ventilated patient is laborious and requires special patient hoists, which are attached to the ICU mast assembly system. Such systems are infrequently available, particularly in the developing world. A similar study of height, weight and BMI estimation in trauma patients in the USA, showed that estimates by both health care providers and patients themselves were only 50% accurate and resulted in inaccurate BMI classification in a third of the cases.[24]

We felt the need for providing an alternative method of estimating BMI, based upon easily measured parameters, which is more reliable than visual estimates currently used in such circumstances.

We used linear regression model for estimating BMI only using two simple parameters, i.e., waist and hip circumference. The inter-observer estimates for waist and hip were not significantly variable or inaccurate. By placing the values of waist and hip in the linear regression equation, we found that the estimated BMIs and actual BMIs agreed well. The difference between the two was not significant, and did not affect the category of BMI in which the patient was placed.

Our method permits prediction of BMI from easily measured parameters such as waist and hip circumference, both of which require minimum equipment, and thus enables us to do away with the need for expensive and highly specialised equipment.

As it has been reported that intra-abdominal or visceral fat is an independent predictor of insulin resistance[25,26], our findings and linear regression model include both BMI and WC, which, when combined, better predict metabolic risk than does either variable alone.

Such an estimation model was introduced in a study conducted in Japan children with the assumption that it is possible to estimate waist circumference from height and weight, at least among the paediatric age groups in Japan. This estimation was proposed to be an alternative way and useful in detecting childhood metabolic syndrome for which a waist circumference figure is necessary, but is not usually available in school health records.[27] We provided a reliable prediction model for the estimation of BMI, which is relies upon parameters conveniently measured even in those patients who have limited mobility or are on life support. Both models have their unique application.

## LIMITATIONS

We only included diagnosed type 2 diabetic patients in our study, and most of these patients were either over weight or obese. Application of this model to non-diabetic patients, as well as lean subjects may lead to less accurate results. The waist and hip measurements were taken in standing posture, so measuring waist and hip circumference in supine patients (immobilised or critically ill ICU patients) may result in somewhat different values than would be obtained with the patient erect.

We included only adult age group of 20 years and above. So the applicability of this prediction model for estimating BMI in younger patients is still to be ascertained.

## FUTURE RECOMMENDATIONS

We recommend future studies to apply linear regression model for prediction of BMI based upon measurements of waist and hip circumference in supine patients who are either immobile or admitted to ICUs.

Estimation of BMI in paediatric age group should also be undertaken using this proposed prediction model. As amount of abdominal fat is expected to increase collinearly with incremental increase in the WC, further work is needed to establish the validity of WC as an independent predictor for visceral and abdominal fat and its correlation with BMI using linear regression model.

## CONCLUSION

Estimated BMI using prediction model is an alternate and reliable method for the calculation of BMI. There is no significant change in the category of BMI in either of the estimated and observed BMI. We conclude that BMI can be reliably estimated with this prediction model, based upon hip and waist circumferences.

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