Comparing factors which affect Visceral Fat Area (VFA) for male and female weight management X participants with chow method and meta regression

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Abstract. The spread of fat in human’s body divided into two parts. The first is subcutaneous fat area and the second is visceral fat area (VFA). The largest fat deposit in human’s body is in the subcutaneous area. This fat is called body fat, while the remains of fat in human’s body is located in visceral area inside abdominal cavity and chest cavity. VFA is a dangerous fat, so this study proposes multiple linear regression models to know how to control VFA level more precisely based on body mass index (BMI), basal metabolic rate (BMR), chronological age, biological age, body fat, and skeletal muscle variables. There is presumption that VFA level and other variables that are considered in weight management are different between male and female, so the regression models for male and female groups are built separately. The Chow test is performed to test the similarity of both regression models for male and female groups. If both regression models for male and female groups are same, the combined regression model will be built for male and female groups which can explain the control of VFA level to relate variables in both male and female.

Keywords: Chow method, meta regression, subcutaneous fat area

1. Introduction

Riset Kesehatan Nasional (National Health Research) 2016 reveals 20.7% of Indonesian adult population are obese. The Global Burden of Diseases study which published in the scientific journal places Indonesia at 10th in the list of countries with the highest obesity rates in the world [1]. These facts make people hope to have an ideal weight that is considered healthy by following some of Weight Management’s programs. In fact, obese people will have high levels of VFA, whereas people with high levels of VFA may not be obese [2]. VFA is fat that's stored within the abdominal cavity around important internal organs of the body, not the fat that lies beneath the skin [3]. Therefore, the Weight Management X Foundation in its practice take into consideration on the levels of VFA in the body. Aside from VFA, there are also other variables such as Body Mass Index (BMI), Basal Metabolic Rate (BMR), chronological age, biological age, body fat, and skeletal muscle.

If the variables which affect VFA and the relationship between these variables are known, the control of the levels of VFA in the human’s body can be done more precisely. The relationship model between VFA variable with other variables in weight management is what will be the main problem in this paper. Some sources state that the levels of VFA and other variables considered in weight management are different between males and females [4-6]. The relationship between VFA and other variables in weight
management can be found using multiple linear regression model. A separate regression model for male and female will be created because there are allegations that the relationship differs between males and females.

In this paper, the study is about to examine the similarity of two models of VFA variable’s relation regression with other variables to find out whether the two regression models between male and female are the same or not using Chow test. If the results of the Chow test show that the regression models between males and females are not similar, then the models for controlling VFA levels in male and female will use their respective regression models. If the Chow test results show that the regression model between males and females are similar, then this study will look for the regression coefficients that combine the two models. This combined regression model will be used in the treatment of VFA levels for both male and female as general. If the result of Chow test shows that the models for males and females are not similar, then each model use to analyze the data for males and females separately.

2. Experimental

2.1. Multiple regression model

A multiple linear regression model with \( k \) regressors and \( n \) observations in matrix form is:

\[
\begin{bmatrix}
Y_1 \\
Y_2 \\
Y_3 \\
\vdots \\
Y_n
\end{bmatrix} = \begin{bmatrix}
1 & X_{11} & X_{12} & \cdots & X_{1k} \\
1 & X_{21} & X_{22} & \cdots & X_{2k} \\
1 & X_{31} & X_{32} & \cdots & X_{3k} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
1 & X_{n1} & X_{n2} & \cdots & X_{nk}
\end{bmatrix}
\begin{bmatrix}
\beta_0 \\
\beta_1 \\
\beta_2 \\
\vdots \\
\beta_k
\end{bmatrix} + \begin{bmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\vdots \\
\varepsilon_n
\end{bmatrix}
\tag{1}
\]

with:
- \( Y \) is \( n \times 1 \) column vector from response variables
- \( X \) is \( n \times p \) matrix from regressor variables with \( p = k + 1 \), \( p \) is the number of parameters in the model (including \( \beta_0 \))
- \( \beta \) is \( p \times 1 \) column vector from model’s parameter
- \( \varepsilon \) is \( n \times 1 \) column vector from random error.

The multiple linear regression model in equation 1 has the following assumption:
1. There are no multicollinearity between regressor variables,
2. Errors are normal distributed,
3. \( \text{Cov}(\varepsilon_i, \varepsilon_j) = 0 \) for \( i \neq j \),
4. \( \text{Cov}(\varepsilon_i, \varepsilon_j) = \sigma^2 \).

The estimation \( \hat{Y} \) can be written as follows:

\[
\hat{Y} = \hat{\beta}.
\tag{2}
\]

The estimation in equation 2 is BLUE (Best Linear Unbiased Estimation) [7].

2.1.1. Test for significance regression. The test for significance of regression is a test to determine if there is a linear relationship between the response \( Y \) and any of the regressor variables \( X_1, X_2, \ldots, X_n \). The appropriate hypotheses are:

\[
H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0
\]
\[
H_1: \text{at least one } j \text{ such that } \beta_j \neq 0, j = 1, 2, \ldots, k
\tag{3}
\]

define:

\[
SS_{Reg} = \sum_{i=1}^{n} (\hat{Y}_i - \bar{Y})^2
\tag{4}
\]
then the test statistic for hypotheses (3) is obtained as follows:

\[
F_0 = \frac{SS_{\text{Reg}}/df_{\text{Reg}}}{SS_{\text{Res}}/df_{\text{Res}}} = \frac{MS_{\text{Reg}}/k}{MS_{\text{Res}}/(n-p)} \sim F_{k,n-p}
\]

(6)

\[H_0\] is rejected with significance level \(\alpha\) if \(F_0 > F_{\alpha,k,n-p}\) [7].

2.1.2. Test on individual regression coefficients. The hypotheses for testing the significance of any individual regression coefficient, such as \(\beta_j\), are:

\[
H_0: \beta_j = 0 \\
H_1: \beta_j \neq 0, j = 1,2,\ldots
\]

(7)

The test statistic for hypotheses (7) is obtained as follows:

\[
t_0 = \frac{\hat{\beta}_j}{s_{\hat{\beta}_j}} \sim t_{a/2,n-p}
\]

(8)

\(H_0\) is rejected with significance level \(\alpha\) if \(|t_0| > t_{a/2,n-p}\) [7].

2.1.3. Checking assumptions of the regression model. Based on the data in this study, (1) VIF (Variance Inflation Factor) > 5 which indicates there are no multicollinearity between regressor variables, (2) Shapiro Wilk test for normality to determine that errors are normal distributed, (3) \(E[\varepsilon] = 0\), (4) Homoscedasticity which could be seen from scatterplot between residuals and prediction values of the model which indicates that Corr[\(\varepsilon_i, \varepsilon_j\)] = 0, \(\forall i \neq j\). (5) Autocorrelation from Durbin Watson’s value which should be near 2 that indicates Cov(\(\varepsilon_i, \varepsilon_j\)) = \(\sigma^2 I\) [7].

2.2. Chow test

The chow test in this paper only used for testing the similarity between two linear regression models. The appropriate hypotheses are:

\[
H_0: \beta_{j1} = \beta_{j2} \forall j = 0,1,2,\ldots,k \\
H_1: \text{at least 2 } \beta_j\text{'s are different}
\]

(9)

then the test statistic for hypotheses (9) is obtained as follows:

\[
F_0 = \frac{SS_{\text{Res}}/\sigma^2 - (SS_{\text{Res1}}/\sigma_1^2 + SS_{\text{Res2}}/\sigma_2^2)/p}{n_1 + n_2 - 2p} \sim F_{p,n_1+n_2-2p}
\]

(10)

\[
SS_{\text{Res}} - (SS_{\text{Res1}} + SS_{\text{Res2}})/p
\]
where $F_0$ is a test statistic that have F distribution with $p$ and $n_1 + n_2 - 2p$ degrees of freedom, $SS_{Res}$ is a combine residuals sum square, $SS_{Res1}$ is residuals sum square of model 1 (male), $SS_{Res2}$ is residuals sum square of model 2 (female). $n_1$ is sample size of data 1 and $n_2$ is sample size of data 2. $p$ is the number of regressors. $H_0$ is rejected with significance level $\alpha$ if $F_0 > F_{a,p,n_1+n_2-2p}$, which indicates the two linear regression models are not similar [8].

2.3. Meta regression

In this paper, meta regression only used to find the combined model from two linear regression models. Let $w_{jc}$ as weight coefficient in regression model. To find the estimation of combined parameter, define:

$$w_{jc} = \frac{1}{\text{Var}(\hat{\beta}_{jc})}; \forall c = 1,2; \forall j = 0,1,2,\ldots,k$$

with $\text{Var}(\hat{\beta}_{jc})$ is the variance of the regression coefficient of the model $c$. Estimation of combined $\beta_j$ is defined as the following:

$$\hat{\beta}_{j\text{\_gab}} = \frac{\sum_{c=1}^{2} w_{jc}\hat{\beta}_{jc}}{\sum_{c=1}^{2} W_{jc}} \forall j = 0,1,2,\ldots,k$$

with the result of the combined linear regression model as follows [9]:

$$\hat{Y}_{gab} = \beta_{0\text{\_gab}} + \beta_{1\text{\_gab}}X_1 + \beta_{2\text{\_gab}}X_2 + \ldots + \beta_{k\text{\_gab}}X_k.$$ (13)

3. Results and discussion

Population in this study is all participants in weight management which managed by Weight Management Foundation X. Sample of 175 respondents are given by Weight Management Foundation X.

Descriptive statistics of each variable involved in this study is showed at table 1.

3.1. The form of multiple linear regression models

The linear regression model for male group is:

$$Y = \beta_{01} + \beta_{11}X_1 + \beta_{21}X_2 + \beta_{31}X_3 + \beta_{41}X_4 + \beta_{51}X_5 + \beta_{61}X_6 + \epsilon_1$$

(14)

The linear regression model for female group is

$$Y^* = \beta_{02} + \beta_{12}X_1 + \beta_{22}X_2 + \beta_{32}X_3 + \beta_{42}X_4 + \beta_{52}X_5 + \beta_{62}X_6 + \epsilon_2$$

(15)

with, $Y$ dan $Y^*$ are VFA level; $X_1$ is BMI; $X_2$ is BMR; $X_3$ is chronological age; $X_4$ is biological age; $X_5$ is body fat; $X_6$ is skeletal muscle; $\beta_{0c}, \beta_{1c}, \beta_{2c}, \ldots, \beta_{6c}$ dan $\beta_{0c}^*, \beta_{1c}^*, \beta_{2c}^*, \ldots, \beta_{6c}^*$ are the model parameters $\epsilon_c = \text{random error} ; c = 1,2$

then the estimation of regression models were obtained as follows, Regression model for male group:

$$\hat{Y} = -73.259 + 1.352X_1 - 0.005X_2 + 0.196X_3 - 0.010X_4 + 0.506X_5 + 1.219X_6$$

(16)
Regression model for female group:
\[ \hat{Y}^* = -24.549 + 1.064X_1 + 0.002X_2 + 0.170X_3 - 0.121X_4 + 0.015X_5 + 0.010X_6 \]  
(17)

with \( \hat{Y} \) dan \( \hat{Y}^* \) is VFA level estimation.

3.2. Testing the significance of the regression models

The hypotheses for male group is:

\[ H_0: \beta_{11} = \beta_{21} = \beta_{31} = \beta_{41} = \beta_{51} = \beta_{61} = 0 \]

\[ H_1: \text{At least one } j \text{ such that } \beta_{j1} \neq 0, j = 1,2,\ldots,6 \]  
(18)

By using test statistic in equation 6 thus obtained the value of statistic \( F = 619.823 \) with degree of freedom 6 and 46 respectively, and \( p - value < 0.001 \).

By using the level of significance \( \alpha = 0.1 \), a decision rule is \( H_0 \) will be rejected if \( p - value < \alpha \).

As \( p - value < \alpha = 0.1 \), thus \( H_0 \) is rejected. The conclusion is at least one \( j \) such that \( \beta_{j1} \neq 0, j = 1,2,\ldots,6 \) By simple means, the model which obtained is sufficient to predict \( Y \).

The hypotheses for female group is:

\[ H_0: \beta_{12} = \beta_{22} = \beta_{32} = \beta_{42} = \beta_{52} = \beta_{62} = 0 \]

\[ H_1: \text{At least one } j \text{ such that } \beta_{j2} \neq 0, j = 1,2,\ldots,6 \]  
(19)

By using test statistic in equation 6 thus obtained the value of statistic \( F = 425.578 \) with degree of freedom 6 and 111 respectively, and \( p - value < 0.001 \).

By using the level of significance \( \alpha = 0.1 \), a decision rule is \( H_0 \) will be rejected if \( p - value < \alpha \).

As \( p - value = 0.0 < 0.1 = \alpha \) thus \( H_0 \) is rejected. The conclusion is at least one \( j \) such that \( \beta_{j2} \neq 0, j = 1,2,\ldots,6 \). By simple means, the model is sufficient to predict \( Y \).

3.3. Testing the similarity between two regression models obtained using Chow test

The hypotheses are:

\[ H_0: \beta_{j1} = \beta_{j2}, j = 0,1,2,3,4,5,6 \]

\[ H_1: \text{At least one } j \text{ such that } \beta_{j1} \neq \beta_{j2} \]  
(20)

By using test statistic in Equation 10, obtained the value of statistic \( F = 16.77328 \) with degree of freedom 7 and 157 respectively, and \( p - value = 1.992 \times 10^{-16} \).

By using the level of significance \( \alpha = 0.1 \), a decision rule is \( H_0 \) will be rejected if \( p - value < \alpha \).

As \( p - value = 1.992 \times 10^{-16} < \alpha = 0.1 \) thus \( H_0 \) is rejected. The conclusion is the parameter of the linear regression model in equation 14 and equation 15 are not similar.
3.4. Prospecting the best linear regression models for male group and female group

In the previous section, the chow test gave the conclusion that the regression models for male group and female group are not similar. Thus, instead of combining two regression models, this part will be prospecting the best linear regression models for male group and female group separately.

Consider linear regression model for male group is:

\[ Y = \beta_0 + \beta_2 X_2 + \beta_3 X_3 + \beta_6 X_6 + \varepsilon_1 \]  \hspace{1cm} (21)

First, the significance of the model in equation 21 will be tested with the hypotheses (18). By using test statistic in equation 6, obtained the value of statistic

\[ t = 13.169 \]  \hspace{1cm} (22)

Then the test on individual regression coefficients have been done with the results showed by table 2.

By using the level of significance \( \alpha = 0.1 \), a decision rule is \( H_0 \) will be rejected if \( p-value < \alpha \). As \( p-value < \alpha = 0.1 \) thus \( H_0 \) is rejected. The conclusion is at least one \( j \) such that \( \beta_{j1} \neq 0, j = 1, 2, \ldots, 6 \). By simple means, the model which obtained is sufficient to predict \( Y \).

The VIF's value for each variable can be seen at table 3.

Table 2. The test statistic and \( p-values \) for each variable in linear regression model for male group.

| \( \hat{\beta}_j \) | \( t-value \) | \( p-value \) |
|-----------------|-------------|-------------|
| \( \hat{\beta}_2 \) | 13.169 | \( < 2 \times 10^{-16} \) |
| \( \hat{\beta}_3 \) | 1.383 | 0.017 |
| \( \hat{\beta}_6 \) | \(-7.652\) | \( 6.53 \times 10^{-10}\) |

Table 3. VIF's value for each variable in linear regression model for male group.

| Regressor variable | VIF  |
|-------------------|------|
| \( X_2 \)         | 1.280|
| \( X_3 \)         | 1.268|
| \( X_6 \)         | 1.532|
Based on figure 1, the scatterplot doesn’t form any pattern, thus the heteroscedasticity does not appear in the model.

The last thing to be done is to find the value of Durbin-Watson statistic, which measure the autocorrelation in model. The value obtained is 2.15. This value appears to be near 2, thus it can be concluded that there is no autocorrelation on the residuals.

The model in equation 21 can be concluded as the best linear regression model for the male group, because all the assumption has fulfilled and all parameters in the model are significant. Thus the model can be rewritten as:

$$\hat{Y} = 4.510 + 0.018X_2 + 0.369X_3 - 0.822X_6$$

(23)

with, $\hat{Y}$ is VFA level estimation; $X_2$ is BMR; $X_3$ is chronological age; $X_6$ is skeletal muscle.

Since the best linear regression model for male group is obtained, the next thing to do is to obtain the best linear regression for female group. Consider the following linear regression model for female group is:

$$Y = \beta_0 + \beta_2X_2 + \beta_3X_3 + \beta_6X_6 + \epsilon_1$$

(24)

The significance of the model in equation 24 will be tested with the hypotheses (19). By using the test statistic in equation 6, obtained the value of statistic $F = 250.232$ with degree of freedom 3 and 115, and $p-value < 0.001$. By using the level of significance $\alpha = 0.1$, a decision rule is $H_0$ will be rejected if $p-value < \alpha$. As $p-value < \alpha = 0.1$, thus $H_0$ is rejected. The conclusion is at least one $j$ such that $\beta_j \neq 0, j = 2, 3, 5$. By simple means, the model is sufficient to predict $Y$.

The results of the test on individual regression coefficients showed by table 4.

Figure 1. Scatterplot between residual and predicted value of regression model for male group.

| $\hat{\beta}_1$ | $t-value$ | $p-value$ |
|-----------------|-----------|-----------|
| $\hat{\beta}_2$ | 14.748    | $< 2 \times 10^{-16}$ |
| $\hat{\beta}_3$ | 4.893     | $3.30 \times 10^{-6}$ |
| $\hat{\beta}_5$ | 8.051     | $8.75 \times 10^{-13}$ |
By using the level of significance $\alpha = 0.1$, a decision rule is $H_0$ will be rejected if $p-value < \alpha$. As $p-value_i < \alpha$ for $\hat{\beta}_j, j = 2,3,5$ thus it can be concluded that $X_2$, $X_3$, and $X_5$ are significant.

The VIF's value for each variable can be seen at table 5.

Table 5 shows that the value of VIF($X_i$) < 5, $i = 2,3,5$ thus it can be concluded that there is no multicollinearity in the model.

The next thing to do is to test the normality of error from the model with Shapiro Wilk test. The following hypotheses are:

\[
H_0: \text{Error is normal distributed} \\
H_1: \text{Error is not normal distributed}
\] (25)

By using the level of significance $\alpha = 0.1$ with a decision rule: $H_0$ will be rejected if $p-value < \alpha$. As $p-value = 0.351 > 0.1 = \alpha$ thus $H_0$ is not rejected and the conclusion is error is normal distributed.

After that, the mean of the errors in the model will be sought. Thus $\[\bar{\epsilon}_i\] = 6.974 \times 10^{-17} \approx 0$.

The heteroscedasticity from the model will be seen from a scatterplot in figure 2.

Based on the scatterplot at figure 2, there is no pattern, thus the heteroscedasticity does not appear in the model.

The following is to find the value of Durbin-Watson statistic, which measure the autocorrelation in the model. The value obtained is 1.7. This value appears to be near 2, thus it can be concluded that the errors are not correlated.

**Table 5. VIF's value for each variable in linear regression model for female group.**

| Regressor variable | VIF  |
|--------------------|------|
| $X_2$              | 1.594|
| $X_3$              | 1.251|
| $X_5$              | 1.790|

![Figure 2. Scatterplot between residual and predicted value of regression model for female group.](image)
The model in equation 24 can be concluded as the best linear regression model for the female group, where all assumptions have fulfilled and all parameters in the model are significant. Thus the model can be rewritten as

\[
\hat{\bar{y}} = -29.188 + 0.017X_2 + 0.071X_3 + 0.365X_5
\]  

(26)

with, \(\hat{\bar{y}}\) is VFA level estimation; \(X_2\) is BMR; \(X_3\) is chronological age; \(X_5\) is body fat.

4. Conclusion

Regression analysis is generally used only for one data set. But in the real data we are faced with two or more categories that have different characteristics, which when used together or only using one model, can result in incorrect conclusion. This paper study how to use a regression model for two groups that have different characteristics. In this case, the data is about visceral fat area (VFA), where the data contains gender variable in the analysis. Due the physical conditions differ between men and women, separate regression modeling is carried out, known as the Chow Method.

The results of this study show that the variables that significantly affect the visceral fat area (VFA) in men are BMR, chronological age, and skeletal muscle while the variables that affect the visceral fat area (VFA) in women are BMR, chronological age, body fat. From this study the Chow method provides a more precise analysis for the data that is actually divided into some large sections, in this case two large sections. So for the analysis of similar data, it is recommended to use the Chow method.

References

[1] WHO Expert Consultation 2004 *Lancet* **363** P157-63
[2] Nesto R W 2005 *Tex. Heart Inst. J.* **32** 387-9
[3] Drolet R et al. 2008 *Int. J. Obesity* **32** 283-91
[4] Blaak E 2001 *Curr. Opin. Clin. Nutr. Metab. Care* **4** 499-502
[5] Demerath E W et al. 2007 *Obesity* **15** 2984-93
[6] Johnstone A M, Murison S D, Duncan J S, Rance K A and Speakman J R 2005 *Am. J. Clin. Nutr.* **82** 941-8
[7] Montgomery D C and Peck E A 1992 *Introduction to Linear Regression Analysis* 2nd edition (New York: Wiley-Interscience)
[8] Chow G C 1960 *Econometrica* **28** 591-605
[9] Borenstein M, Hedges L V, Higgins J P T and Rothstein H R 2009 *Introduction to Meta-Analysis* (West Sussex: John Wiley & Sons, Ltd)