Assessment of Bone Density Predictors And the Similarity of Bone Densities Between Female Twins

Joey Hua[1], Jiangtian Guan[2]

[1] University of California, Davis, Department of Statistics

[2] University of California, Davis, Department of Environmental Science and Policy

Abstract

It is widely recognized that as people age, their bones become weaker and more prone to injury. Age aside, however, it is not clearly understood exactly what factors contribute to this loss of bone density. There are presumably a variety of factors that are predictive of bone density, such as height, weight, and lifestyle. We are interested in determining which variables serve as adequate linear predictors of bone density. Furthermore, the bone densities of twins may progress similarly over time; thus, we are also interested in whether or not the bone densities of twins are linearly correlated. Using data collected from 41 pairs of female twins, we performed regression analyses. Our results suggest that age is a predictor for the densities of the lumbar, femoral neck, and femoral shaft; and height is also a holistic predictor for femoral bone densities. In addition, we found general linear correlations between the bone densities of twins. However, our data is not sufficient to suggest whether this association is different in monozygous and dizygous twins.

Introduction

Bone health has long been a concern for people because bones tend to become more vulnerable and prone to injury as people age. One critical indicator of bone health is bone density, which may be affected by a variety of factors. In this study, we are particularly interested in the densities of three types of bones: lumbar, femoral neck, and femoral shaft. Our study will consist of two parts. In the first part, we aim to find out the actual predictors of bone density. We will narrow down our assessment of bone density predictors to eight quantitative ones of an individual: age, height, weight, cups of tea consumed per week, cups of coffee consumed per week, number of alcoholic drinks consumed per week, number of cigarettes consumed per day, and years of smoking. We will also have one qualitative possible predictor: menopause status. In the second part of this study, we will introduce another qualitative predictor, zygotes, to study the possible correlation/predictivity between the bone densities of pairs of twins. We will also compare the results from monozygous twins and dizygous twins and examine whether there is a significant difference between the correlation between those two types of twins.

Method

Part I: Predictors of Bone Density

In order to choose an optimal stepwise regression approach, we started with plotting each of the eight quantitative independent variables against each of the three measures of bone density for a basic visual sense of correlation (Fig. 1.1). The graphs of some of the variables did not seem to show linear relationships at all, and we justified this judgment with a series of t-tests for each of them. At this point, it seemed to us that backward selection would be the most effective approach in eliminating the irrelevant factors and finding out the true predictors. Therefore, we performed a multiple regression with the eight variables for each of the three densities and started excluding ineffective variables based on their p-values. With a threshold of $p \leq 0.05$, we were able to find that lumbar density can only be effectively predicted by age and that femoral neck density can only be effectively predicted by age and height holistically.

While our results showed that age, height, and weight were statistically significant predictors of femoral shaft density, our model violated the normality assumption of the residuals. Therefore, we performed a box-cox transformation on our original model in an attempt to address this issue. However, the transformed model also violated the normality assumption. Nevertheless, a partial F-test showed that removing weight from the model significantly decreased the predictive precision of femoral shaft density. We will interpret and further discuss our data in the next section.

Part II: Bone Density in Twins

Besides external factors, we were also interested in assessing whether the bone densities of twins are linearly correlated. To find out, we designed a simple procedure, which will be repeated for several times. We randomly designated the bone density (lumbar, femoral shaft, and femoral neck, separately) of one twin in each pair into the predictor group (X) and that of the other into the response group (Y); we then plotted X versus Y to see if there is any correlation between the two groups. In total, we created three scatter plots. We analyzed the model summaries and residual plots to determine if a linear correlation could be concluded.

Having assessed the general predictivity of the bone densities between twins, we split up the twins into two groups based on their twin type (monozygous or dizygous) in order to see if there was any difference in bone density prediction between the two types of twins. We repeated the previous procedure and created six more scatter plots. We performed statistical analyses to evaluate whether there is a significant difference between the above-mentioned correlations of the two twin types.

Data and Discussion

Part I: Predictors of Bone Density

Our models are (all values rounded to 2 decimal places for readability):

Lumbar Density = 1.10 - 6.65^{-3} (age)
Femoral Shaft Density = -0.20 - 5.31^{-3} (age) + 8.65^{-3} (height) + 2.27^{-3} (weight)
Femoral Neck Density = -0.45 - 3.67^{-3} (age) + 8.03^{-3} (height)

Our model showed that age was the only predictive variable of lumbar bone density. We observed a p-value of 1.19^{-8} and an F-statistic of 40.38. Although the multiple R^2 of 0.34 was relatively low, it does not nullify the precision of our model because of the extremely small p-value and high F-statistic. The residual plot demonstrated no violation of normality and constant variance assumptions (Fig. 1.2). Partial F-tests showed that adding other possible predictors, such as height and weight, significantly increased the residual sum of squares and reduced the precision of our model to a statistically significant degree. With all this in mind, it is likely that age is the only effective variable (out of the possible variables we had) in predicting the lumbar density of a woman.

Our femoral shaft density model yielded a high F-statistic of 19.27 and a moderately high adjusted R^2 of 0.40. The residual plot displayed a clear curvature which violated the normality assumption of our model (Fig. 1.3), leading us to perform a box-cox transformation on the femoral shaft values. The transformed residual plot was slightly less curved, but we still observed a clear downward trend in residuals. Despite these complications, a partial F-test showed that a regression model with weight included as a predictor was more precise than one without, to a statistically significant degree (with a p-value of 0.01). The apparent violation of normality in the residual plot of our model may or may not be due to chance; nonetheless, a woman's weight is likely to be of use when trying to predict her femoral shaft density. Further partial F-tests showed that age and height both individually reduced the model's residual sum of squares by a statistically significant degree, thus improving predictive precision. In brief, it is likely that, on average, age, height, and weight are all effective predictors of a woman's femoral shaft density.

Age and height were shown to be significant predictors of bone density in the femoral neck. Our model yielded a high F-statistic of 24.47 and an adjusted R^2 of 0.37. The residual plot displayed no violation of normality and constant variance assumptions (Fig. 1.4). With all this in mind, it is likely that, on average, a woman's age and height can accurately predict her femoral neck density.

<u>Part II: Bone Density in Twins</u>

Our models are (all values rounded to 2 decimal places for readability):

All twins:

Lumbar Density = 0.10 + 0.83 (age)
Femoral Shaft Density = 0.17 + 0.82 (age)
Femoral Neck Density = 0.19 + 0.72 (age)

Monozygous twins:

Lumbar Density = 0.07 + 0.89 (age)
Femoral Shaft Density = 0.16 + 0.76 (age)
Femoral Neck Density = -0.90 + 0.90 (age)

Dizygous twins:

Lumbar Density = 0.08 + 0.84 (age)
Femoral Shaft Density = 0.21 + 0.68 (age)
Femoral Neck Density = -0.93 + 0.88 (age)

All scatter plots showed clear positive, linear relationships between the bone densities of twins (Fig. 2.1). The residual plots of our models showed no violation of the normality and constant variance assumptions. (Fig. 2.2).

The estimated slopes of all three models are greater than 0.70 and yielded *p*-values that are significant beyond the 99.9% significance level, and multiple R^2 values higher than 0.40. Therefore, it is likely that, on average, the bone density of one female twin can be used to predict the bone density of the other twin to at least 70% accuracy.

We saw no evidence to suggest that monozygous twins have more closely correlated bone densities than dizygous twins, or *vice versa*. There were no glaring discrepancies in statistical values such as estimated slopes, *p*-values, or R^2 to suggest any possible differences.

Conclusion

In short, the first part of our regression analyses shows that age is a very strong predictor for all three kinds of bone density: lumbar, femoral neck, and femoral shaft. In addition, height is an effective predictor for femoral densities and weight can be significant in predicting the femoral shaft density. This part of our analyses reveals that lifestyle factors like the consumption of tea, coffee, or alcohol have little correlation with one's bone densities. In the second part, we discovered that the bone densities of one twin are, on average, predictive of those of the other twin. This may lead to a variety of future practical implications in the health field. However, we are not able to conclude whether their twin type (monozygous or dizygous) affects the correlation between their bone densities.

Furthermore, our study suggests several directions in which future research is necessary for a better understanding of bone density. Larger sample size should be taken, with equal emphasis on all age and weight groups. Other possible predictors such as diet and workout frequency/intensity should also be assessed, as studies have shown that calcium and exercise can enhance bone health. In addition, we suggest that there needs more research on the bone density in males, between male twins, and between twins of different sexes in order to determine whether or not these same predictors hold for males.

Appendix 1. Graph Key: Units used in this study

- The bone densities of lumbar, femoral neck, and femoral shaft: g/cm^2.
- Height: cm.
- Weight: kg.
- Tea, Coffee: cups/week.
- Alcohol: drinks/week.
- Smoke: cigarettes/day.
- Packyrs: years.
- Lumbar = lumbar density
- Fshaft = femoral neck density
- Fneck = femoral neck density

Appendix 2. Figures

Fig. 1.1

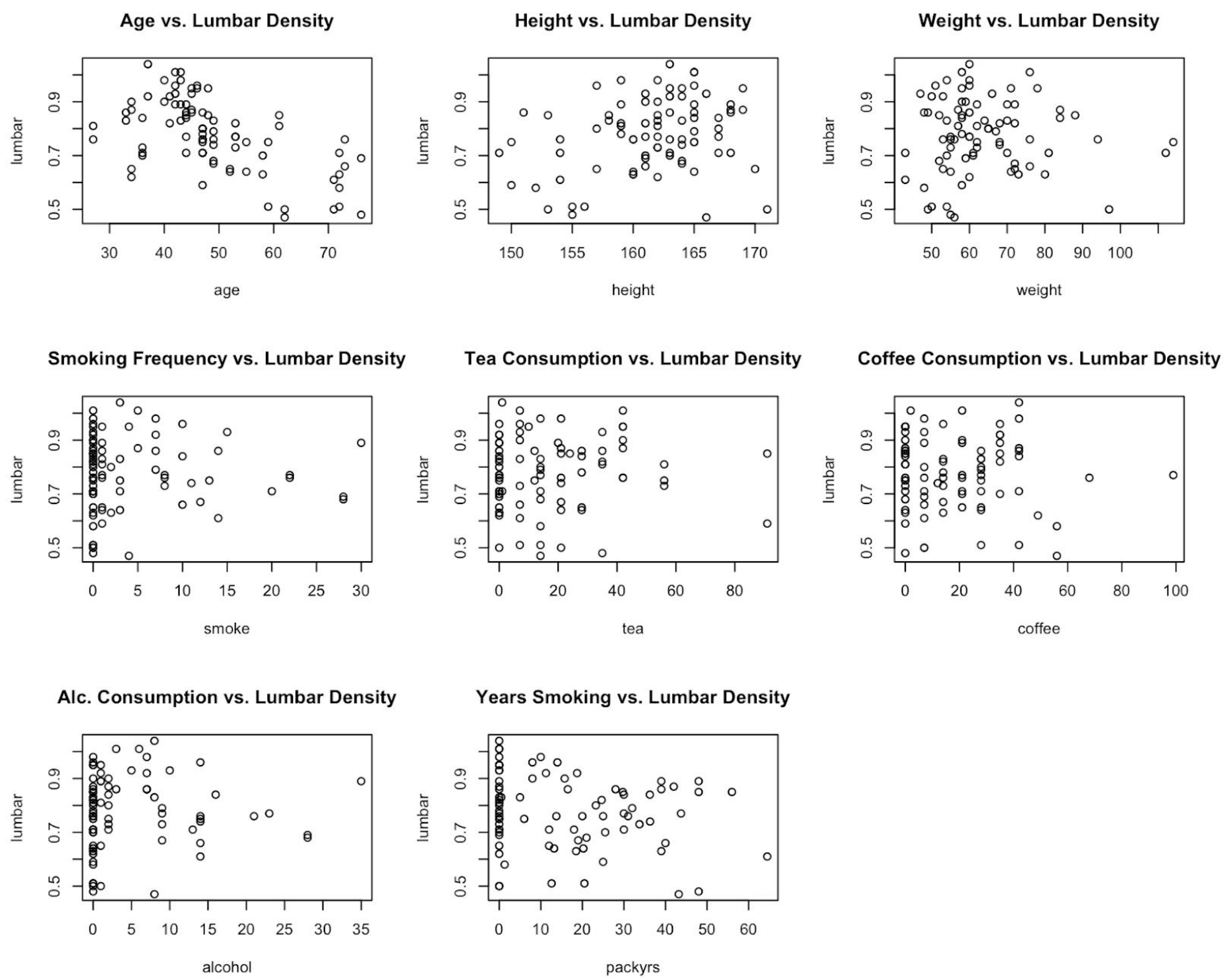


Fig. 1.1, cont.

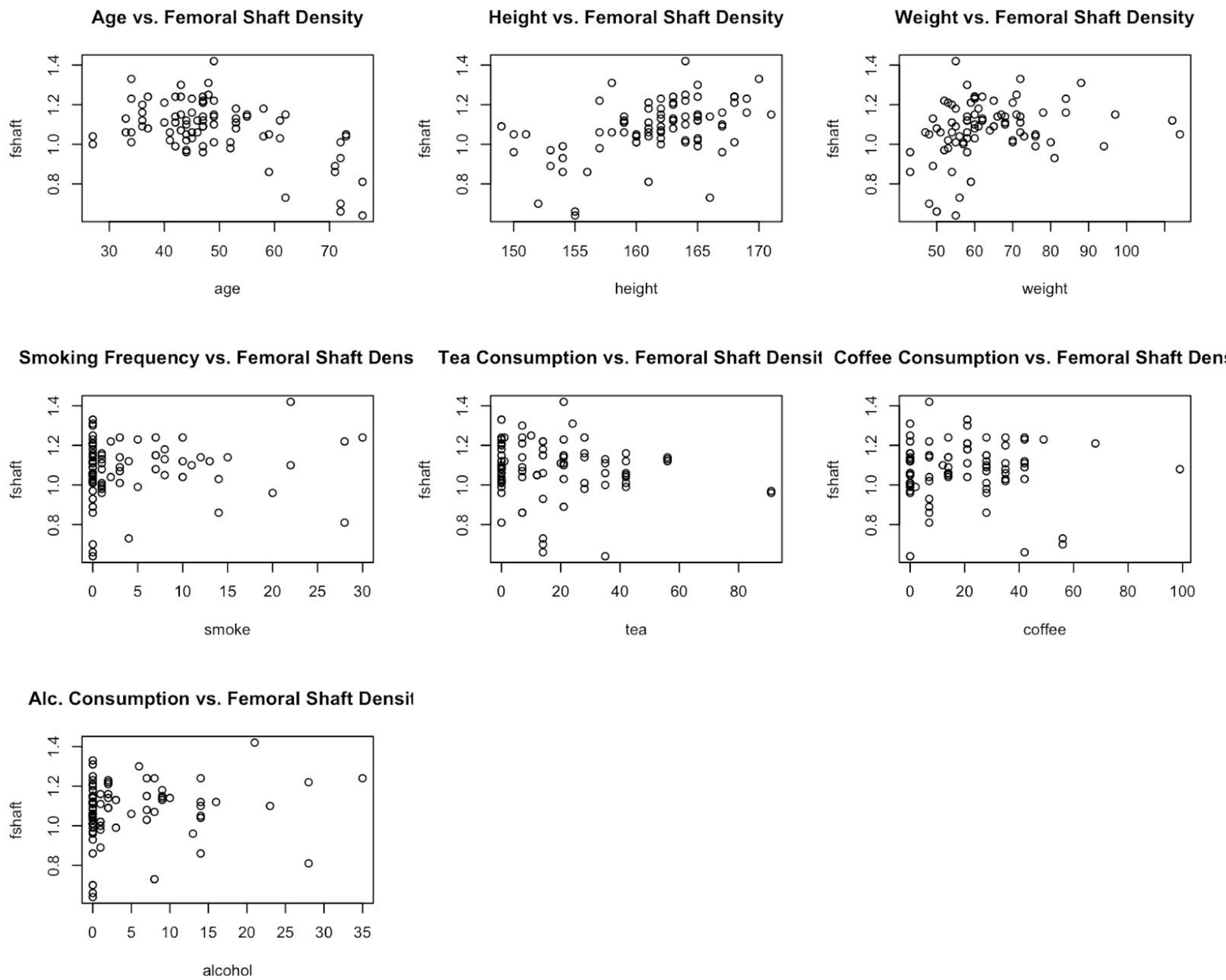

Age vs. Femoral Shaft Density
fshaft
age
Height vs. Femoral Shaft Density
fshaft
height
Weight vs. Femoral Shaft Density
fshaft
weight
Smoking Frequency vs. Femoral Shaft Dens
fshaft
smoke
Tea Consumption vs. Femoral Shaft Densit
fshaft
tea
Coffee Consumption vs. Femoral Shaft Dens
fshaft
coffee
Alc. Consumption vs. Femoral Shaft Densit
fshaft
alcohol

Fig. 1.1, cont.

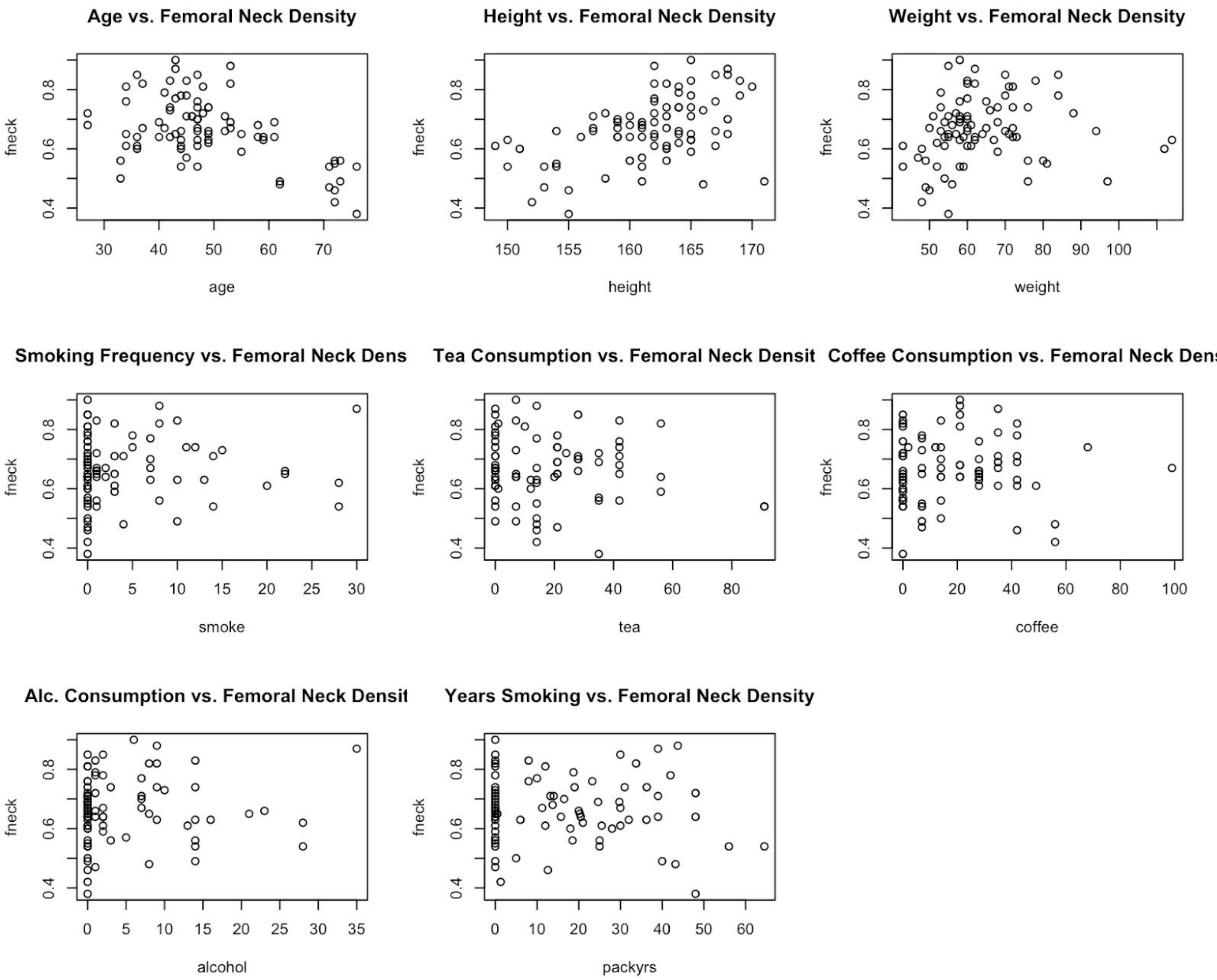
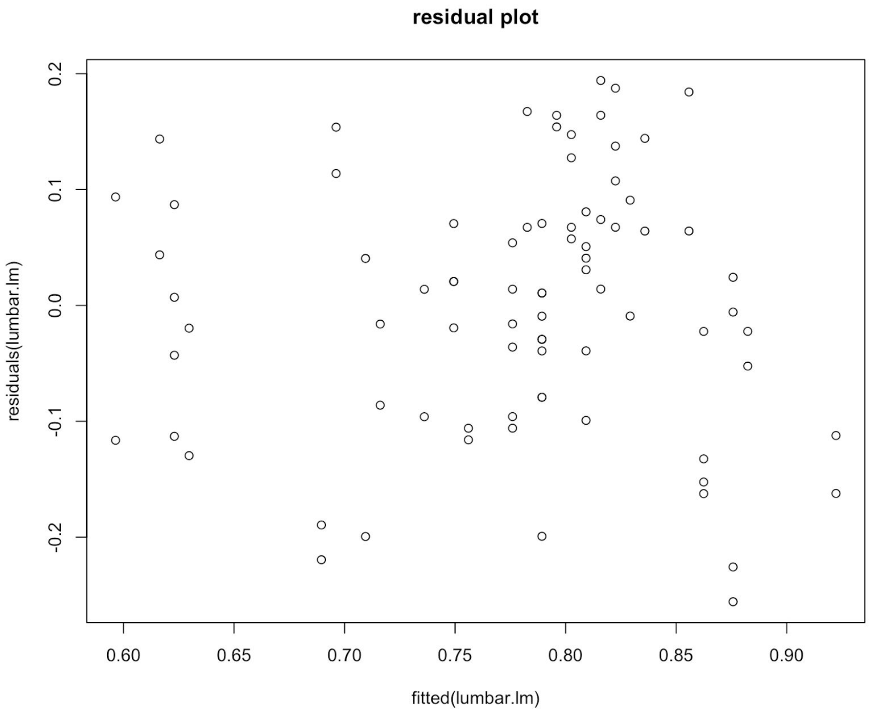

Age vs. Femoral Neck Density
fneck
age
Height vs. Femoral Neck Density
fneck
height
Weight vs. Femoral Neck Density
fneck
weight
Smoking Frequency vs. Femoral Neck Dens
fneck
smoke
Tea Consumption vs. Femoral Neck Densit
fneck
tea
Coffee Consumption vs. Femoral Neck Dens
fneck
coffee
Alc. Consumption vs. Femoral Neck Densit
fneck
alcohol
Years Smoking vs. Femoral Neck Density
fneck
packyrs

Fig. 1.2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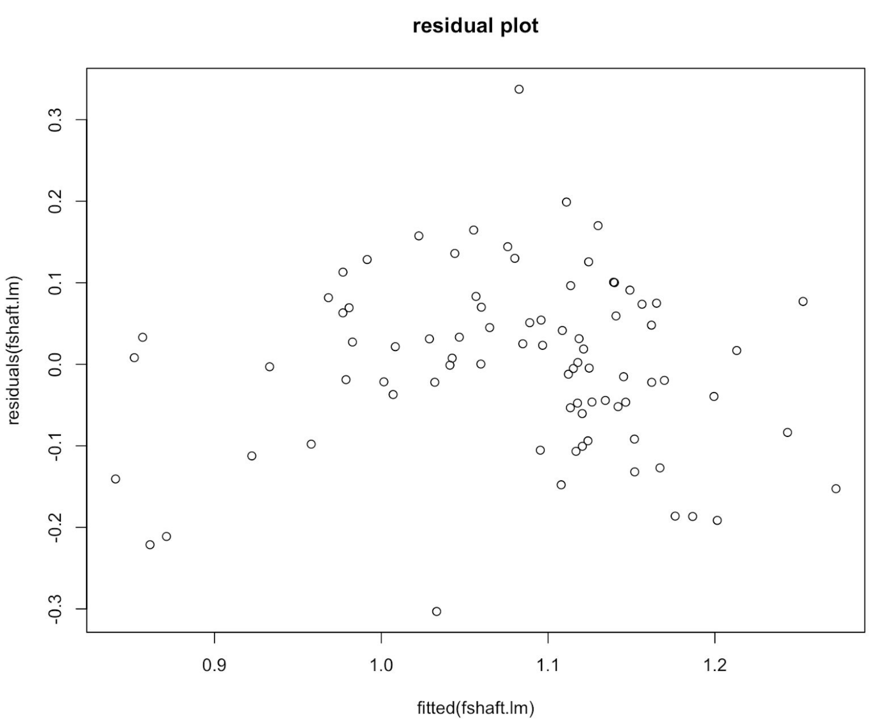
0.2
0.1
0.0
-0.1
-0.2
residuals(lumbar.lm)
0.60
0.65
0.70
0.75
0.80
0.85
0.90
fitted(lumbar.lm)

Fig. 1.3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0.2
0.1
0.0
-0.1
-0.2
-0.3
residuals(fshaft.lm)
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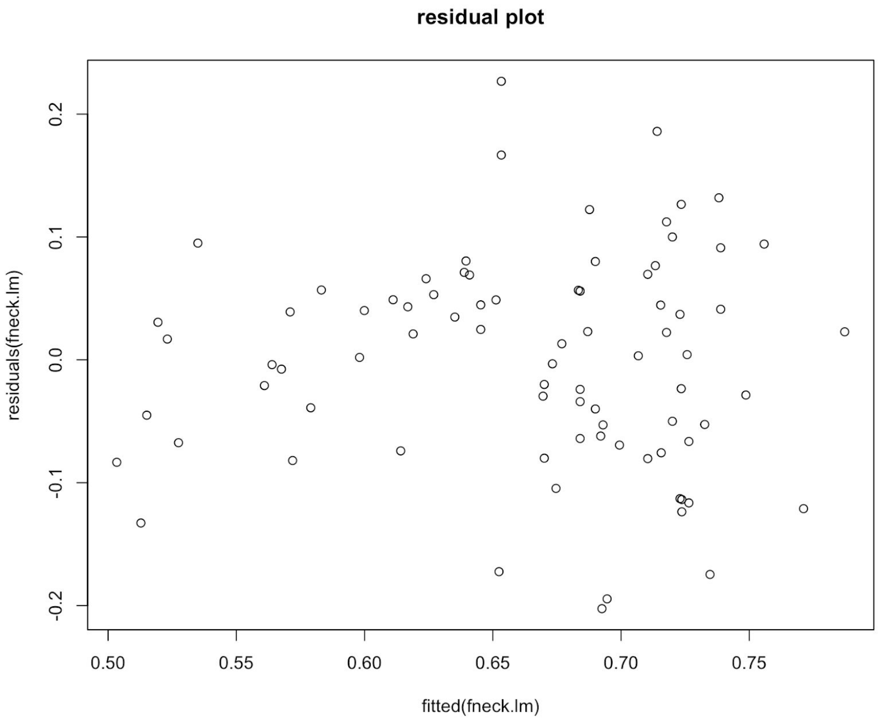
1.1
1.2
fitted(fshaft.lm)

Fig. 1.4


residual plot
residuals(fneck.lm)
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0.1
0.0
-0.1
-0.2
0.50
0.55
0.60
0.65
0.70
0.75
fitted(fneck.lm)

Fig. 2.1

Lumbar_1 = Lumbar density of twin #1
Lumbar_2 = Lumbar density of twin #2
Fshaft_1 = Femoral Shaft density of twin #1
Fshaft_2 = Femoral Shaft density of twin #2
Fneck_1 = Femoral Neck density of twin #1
Fneck_2 = Femoral Neck density of twin #2

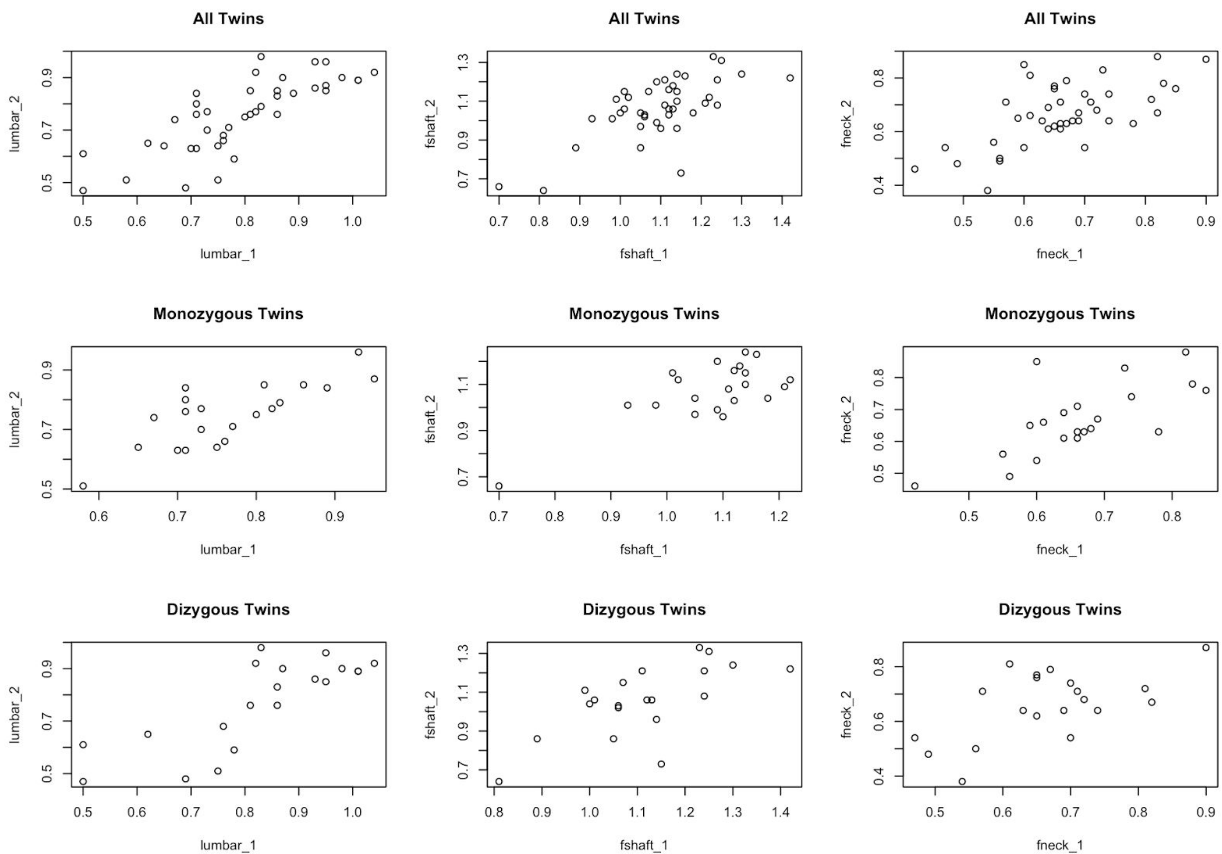
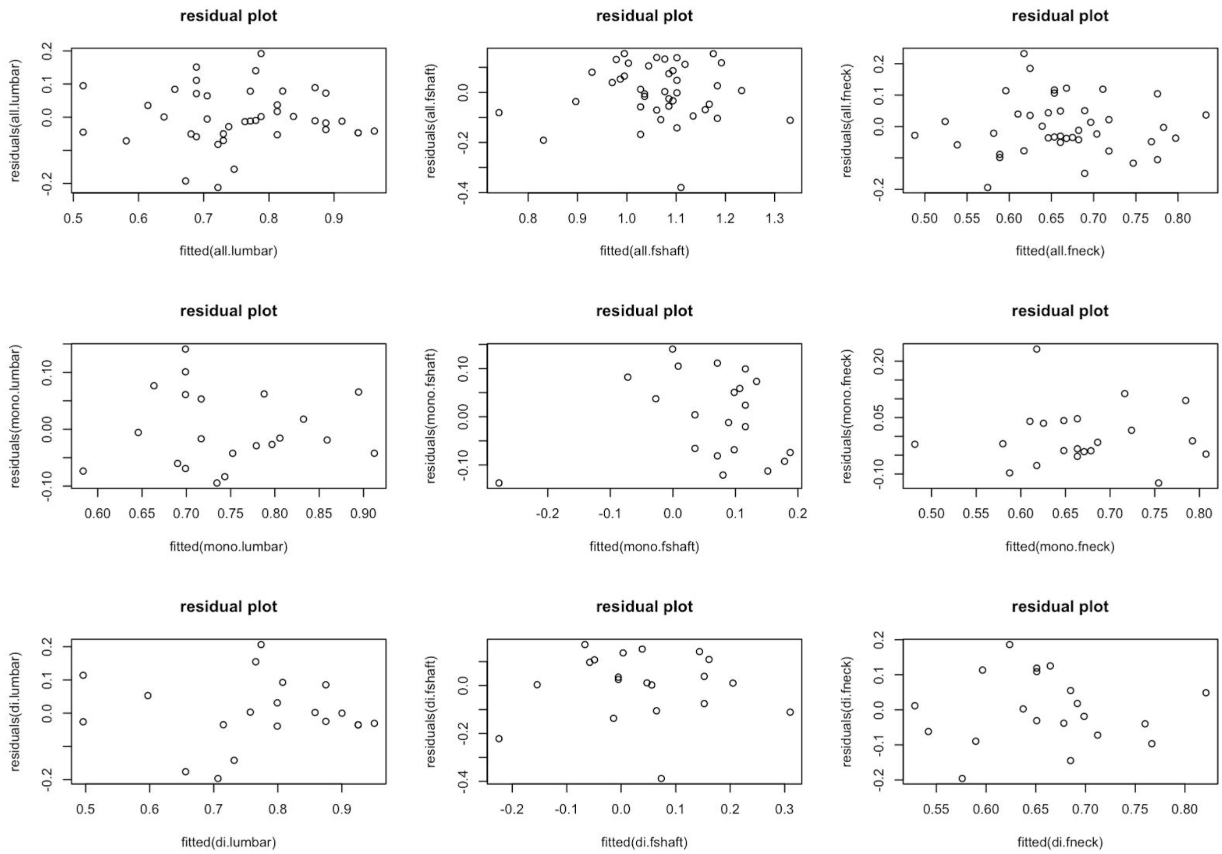


Fig. 2.2


residual plot
residuals(all.lumbar)
fitted(all.lumbar)
residual plot
residuals(all.fshaft)
fitted(all.fshaft)
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residuals(all.fneck)
fitted(all.fneck)
residual plot
residuals(mono.lumbar)
fitted(mono.lumbar)
residual plot
residuals(mono.fshaft)
fitted(mono.fshaft)
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residuals(mono.fneck)
fitted(mono.fneck)
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residuals(di.lumbar)
fitted(di.lumbar)
residual plot
residuals(di.fshaft)
fitted(di.fshaft)
residual plot
residuals(di.fneck)
fitted(di.fneck)