SIZE STREAM Body F.A.T.™
Formulas of Adipose Tissue

June 2019

Size Stream has developed new formulas for estimating human body fat content via the Size Stream SS20 3D body scanner using machine learning. In addition, a new formula using manual measurements has also been developed. A significant new finding during this process was that the optimal body measures to predict body fat are different for the lean versus obese ends of the body fat spectrum of subjects. A combined formula has been developed utilizing this knowledge.

These formulas were developed and cross-validated using a diverse set of over 1790 human 3D body scans (of 179 individuals) whose body composition was also measured using a state-of-the-art four-component body composition model. The four-component model (4C) takes into account the human body's four main molecular components: water, fat, bone mineral, and protein/residual. In order to obtain these compartments, estimates of body volume, water content, bone mineral, and total body mass are needed. These variables were provided via air displacement plethysmography (Cosmed BOD POD® Gold Standard), bioimpedance spectroscopy (ImpediMed® SFB7), dual-energy x-ray absorptiometry (GE Lunar Prodigy), and a calibrated body mass scale, respectively. The variables were then inserted into a validated equation (Wang et al. 2002, American Journal of Clinical Nutrition) in order to estimate 4C body fat. A 4C model is considered a true criterion method of body composition assessment. While many body composition assessment methods validate their products using well-respected single-assessment devices (such as DXA), validation using the 4C represents a notable strength of the new Size Stream formulas. Machine learning techniques were utilized to correlate the 3D body scan data to the 4C body composition measurements. The resulting formulas were then cross-validated using two additional test groups of subjects at separate labs.

The 3D body scans and 4C data were taken at the Department of Kinesiology and Sport Management at Texas Tech University under the oversight of Dr. Grant Tinsley. The 3D body scans were captured using the Size Stream SS20 body scanner. The validation data sets of over 300 body scans were taken at Pennington Biomedical Research Center at Louisiana State University under the oversight of Dr. Steven Heymsfield and at University of California San Francisco and the University of Hawaii Cancer Center under the oversight of Dr. John Shepherd. The 3D scans at the validation sites also used the Size Stream SS20 3D body scanner, and the DXA scans were captured using the Hologic/A DXA scanner. One hundred percent of all the body scans captured and provided to Size Stream were used in the analysis.

To simplify the presentation, a particular group of measures in the subsequent discussion are referred to as the "Muscle to Stomach Index", or MSI. This is a simply an ad hoc reference term that refers to the following measurement combination:

$$Muscle\ to\ Stomach\ Index\ (MSI) = \frac{\text{RBicep} + \text{LBicep} + \text{RCalf} + \text{LCalf} + \text{RThigh} + \text{LThigh}}{\text{Maximum Stomach}}$$

All the measures in this index are circumferences.

-The formula for below mean body fat individuals utilizes just three variables (noting that MSI is a seven variable combination in itself): Gender, Thigh Circumference and MSI Index.

$$BodyFat\ (\sim below\ mean) = f(Gender, Thigh\ Circumference, MSI)$$

-The formula for higher body fat individuals is gender independent and uses just three variables: Gender, Abdomen Circumference, and Total Body Surface Area.

$$BodyFat\ (\sim above\ mean) = f(Gender, Abdomen\ Circumference\ , Body\ Surface\ Area)$$

A decision/regression tree analysis was performed to identify what key identifying factor separates the lower versus higher body fat regimes. It was determined that the Abdomen Circumference was the significant factor and the criteria separation point was 40.75 inches of circumference, and roughly corresponded to the 25% body fat level. The statistical presence of maximum stomach circumference and abdomen circumference coincides with numerous prior studies indicating the importance of these measures in determining the presence of Abdominal Adipose Tissue, and its contribution to total body fat. Abdomen Circumference of 40.75 inches split the test population very close to the midpoint based on body fat %. The next most significant factor in both branches of the regression tree was “Gender”.

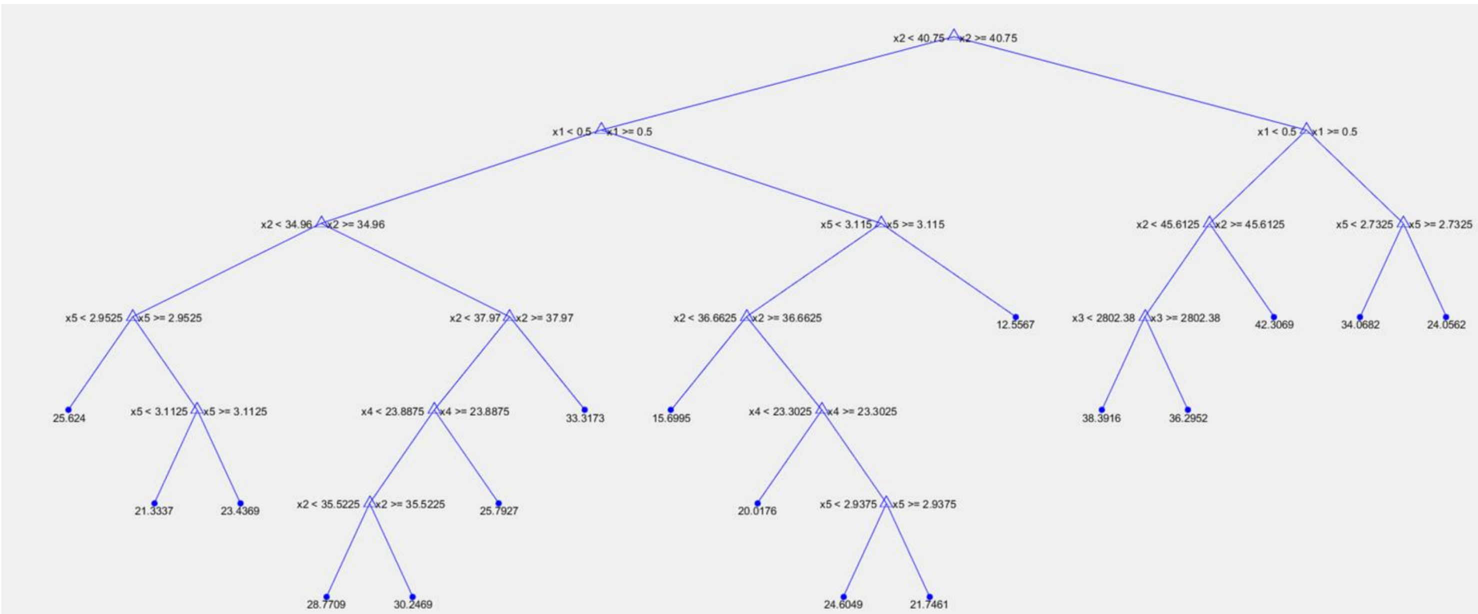

Figure 1 Regression Tree Analysis, X2 = Abdomen Circumference

Alternatively, a blending function in the close region around the domain of 40.75 inch Abdomen Circumference can be utilized, as both functions are effectively equivalent in that region.

Stepwise and Lasso Regression analysis was performed to develop the detailed formulas based on the variables presented. Approximately 200 measures from the Size Stream SS20 automatic measurement software were considered. The detailed formula results are:

$$\boldsymbol{BodyFat}\,\%(\boldsymbol{Abdomen\ Circumference} < \ \mathbf{40.75}\ \boldsymbol{inches})$$

$$= 48.837 - 7.2745\ (*\ 1\text{ for male}, *\ 0\text{ for female}) + 1.192 * Right\ Thigh\ Circ - 17.387 * MSI$$

$$\boldsymbol{BodyFat}\,\%(\boldsymbol{Abdomen\ Circumference} > \ \mathbf{40.75}\ \boldsymbol{inches})$$

$$= -1.1789 - 3.5143\ (*\ 1\text{ for male}, *\ \ 0\text{ for female}) + 1.3664 * Abdomen\ Circ - 0.0069449 * Body\ Surface\ Area$$

Where

$$Muscle\ to\ Stomach\ Index\ (MSI) = \frac{\text{RBicep} + \text{LBicep} + \text{RCalf} + \text{LCalf} + \text{RThigh} + \text{LThigh}}{\text{Maximum Stomach}}$$

Units of measure are “inches” of circumference and “square inches” of surface area.

This result avoids the pitfall of "overfitting" by leveraging only a small number of variables. One can observe that the <40.75 Bodyfat result is one that can easily be computed by taking 7 manual circumference measures, plus gender, albeit the accuracy would be dependent on an accurate manual measurement process. The measure process could be simplified further by taking one bicep/calf/thigh and doubling those values, leaving only 4 manual measures to be taken.

The new formulas yield impressive results with R^2 (R SQUARED) > 0.9 in terms of lbs fat mass between the 4C data set and the estimate from the 3D body scan. The mean difference over the full data set is 0.13 lbs and the STD in terms of body fat percent difference is below 3 percent. The following figure illustrates the data comparison of the 4C body fat result (TT 4C fat mass) and the estimate from the Size Stream SS20 body scan showing the excellent correspondence at both the low and high ends of the population spectrum.

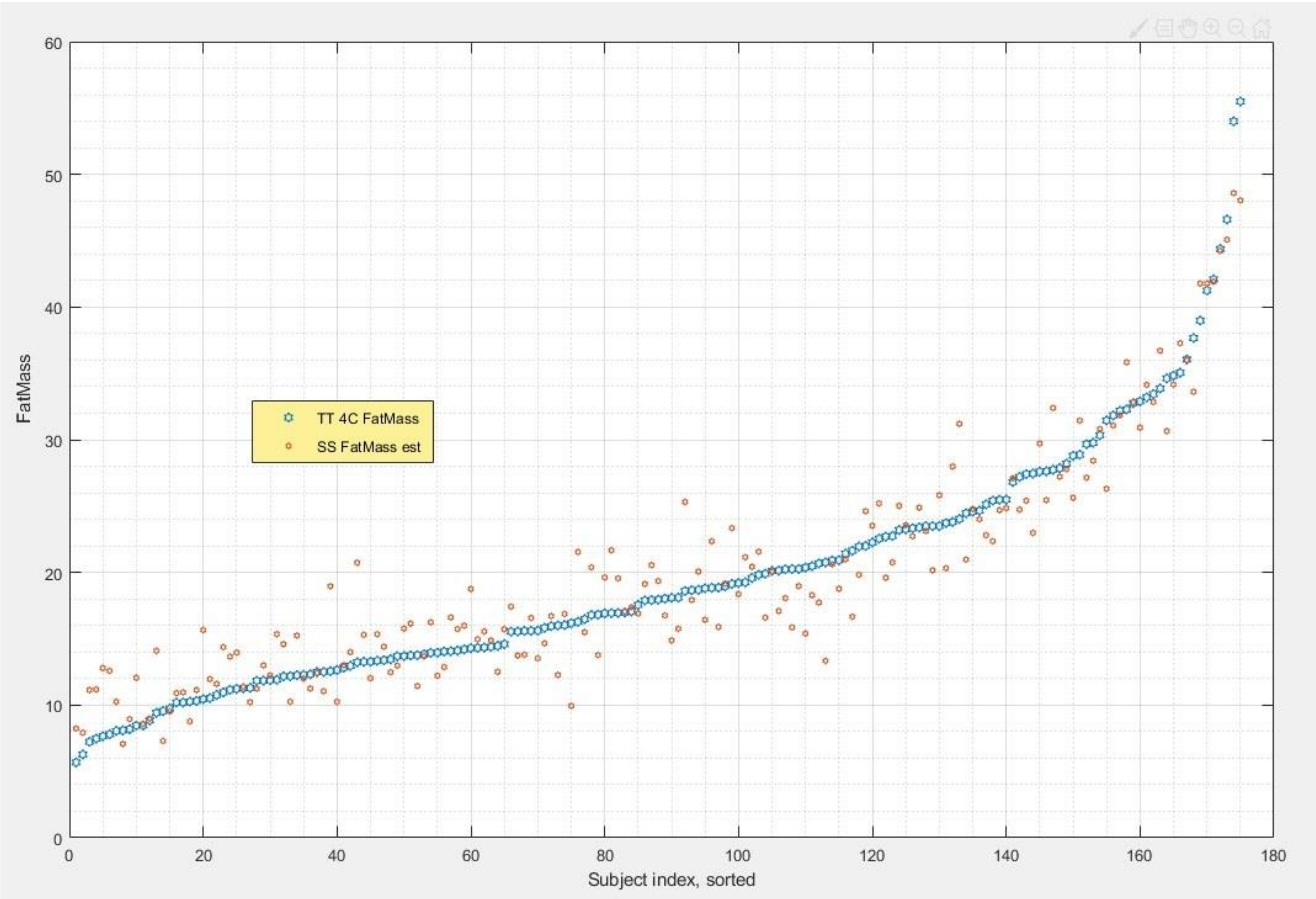

Figure 2 Size Stream Fat Mass versus 4C model (lbs)

To validate this result the developed formula was tested against the two validation data sets which used a DXA body fat estimate only, but still viewed as highly accurate, and perhaps the best result one can get by measuring with only a single device. The results over both test groups were R^2 ~ 0.8 with a mean difference of ~ 1.5 lbs of fat mass.

The following figure shows the result using only the portion of the formula specified for Abdomen Circumference < 40.75 inches. Additional deviation occurs in the high body fat regime without the incorporation of Abdomen Circumference and Total Body Surface Area into the equations, with the predicted result being lower than that measured by the 4C model. A three dimensional measuring system is required to produce Total Body Surface Area, or one could use estimates of surface area available based on height and weight.

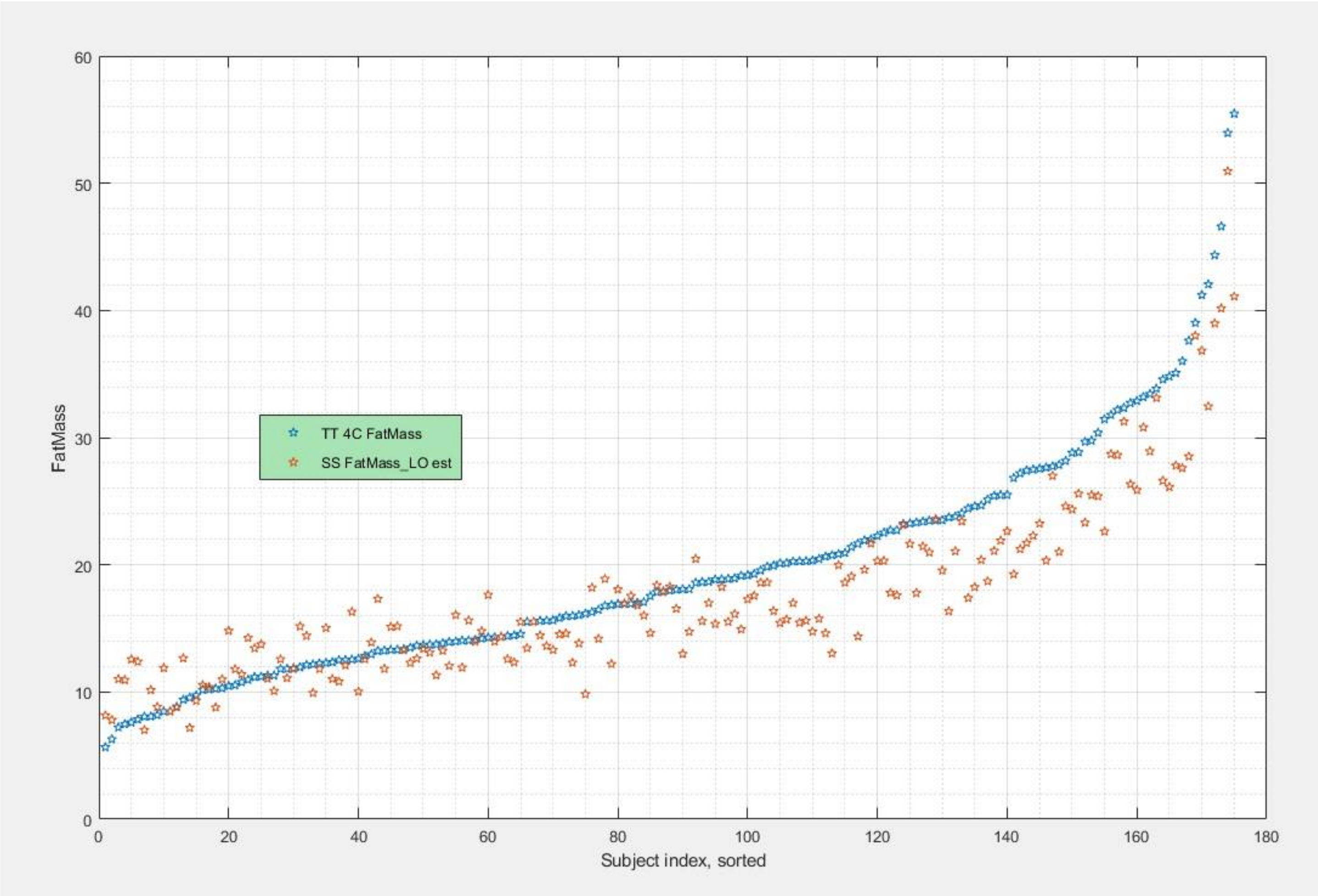

Figure 3 Fat Mass prediction only using the formula for Abdomen Circumference < 40.75

Measurement Definitions:

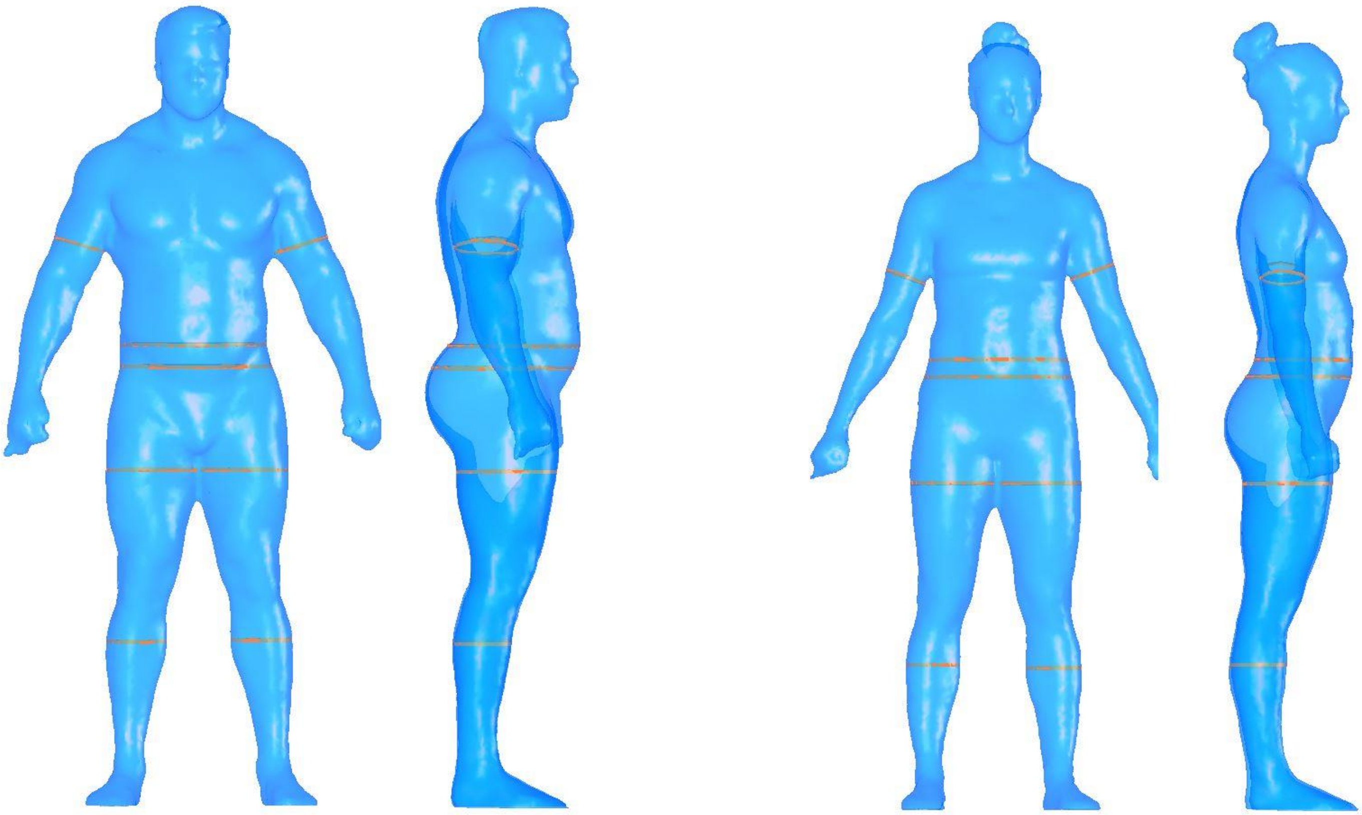

Figure 4 Body Scanner Measurement Locations

Measurement Definitions:

Abdomen Circumference: A horizontal circumference at the forward most projection point between the front waist point and the level of the maximum seat rear projection (between the waist and seat height).

Calf Circumference: The maximum girth measured above the ankle but below the knee.

Bicep Circumference: The largest girth in the upper arm.

Thigh Circumference: The leg girth measured two inches below the crotch point.

Maximum Stomach Circumference: The maximum horizontal circumference taken above the waist but below the bust/chest point.

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References and Information Links:

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https://en.wikipedia.org/wiki/Decision_tree_learning

Lasso and Stepwise Regression:
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Regression Validation (R^2):
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