Categorizing the Morbidly Obese Body Shape and Estimating Body Appearance Outcome before Weight Loss Surgery Using 3D Anthropometric Data

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1. Introduction

Categorizing the physical shape of the morbidly obese has always been an inexact science. Surgeons can readily identify extreme shapes such as "android[1]" or "gynecoid[2]," but will have various opinions as to the shape individuals that present between these two extremes. Yet the physical shape characteristics of a morbidly obese person is often an indicator as to the potential difficulty of the pending surgery[3]. A new set of mathematical equations has been developed to classify "Primary Shape" and "Shape Tendency." These were developed using linear and circumferential measurements, volume and surface data, and the height of certain measurements provided by 3D booth scanning of morbidly obese individuals. With few exceptions, it has been found that these "Shape Descriptors" remain consistent throughout the massive weight loss experience. This finding, combined with longitudinal data collected by scanning, aggregating and de-identifying thousands of individuals who underwent a bariatric surgical procedure offers a statistical approach to estimate body appearance outcome prior to actual weight loss surgery. In turn, this provides a realistic motivational tool to the morbidly obese individual and opens up avenues within the Body Image Assessment and Body Image Dissatisfaction realms of research.

This work complements another paper written for the 2015 conference entitled "Longitudinal Statistical Analysis of Weight, Volume, Surface Area and Circumferential Measurements for a Female Bariatric Population[5] " and uses those statistical findings together with the Shape Descriptor equations set forth in this paper.

Figure 1 displays the two extreme body shapes of morbidly obese individuals.

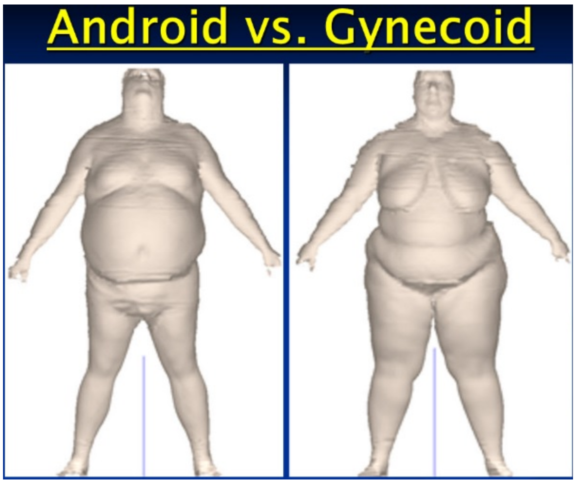
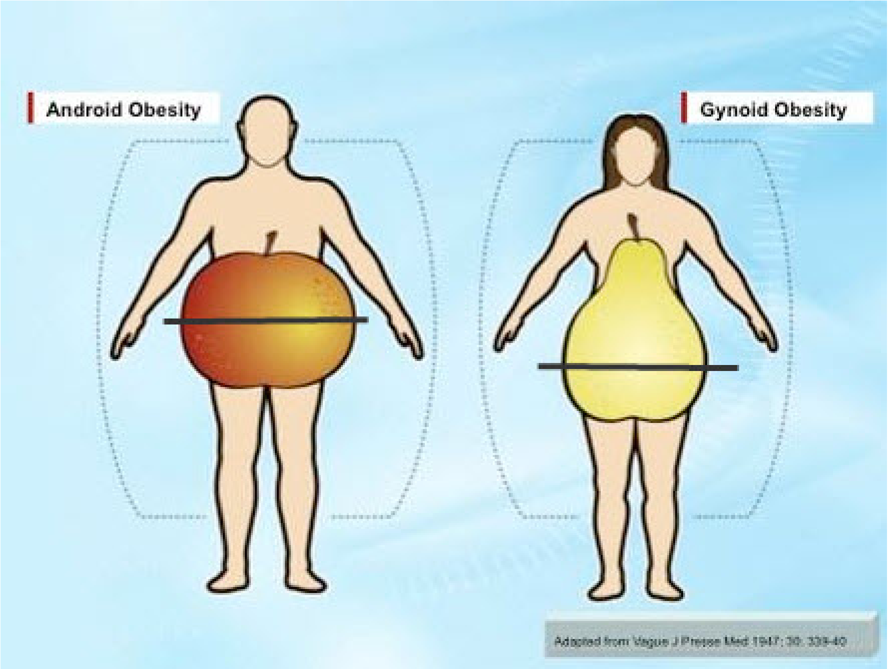


Figure 1. Two Extreme Morbidly Obese Body Shapes

The female on right is what one might consider a "classic" gynecoid shape. She possesses a larger hips measurement relative to her waist measurement, and her upper torso has generally less circumference than her hips. The majority of her excess weight is concentrated about her hips and thighs. One may visualize her shape outline as similar in form to a "pear-shaped" fruit. The male on the left would be considered as the "classic" android shape. He has a high concentration of body weight around his waist accompanied by relatively thin thigh circumferences. One may readily visualize his shape outline as similar to an "apple-shaped" fruit[4]

Figure 2 illustrates further illustrates these basic shapes superimposed on two models.



Adapted from Vague J Presse Med 1947; 30: 339-40

Figure 2. Weight Distribution and Maximum Circumference Android vs. Gynecoid

Conceptually, looking at the pear and the apple it can be seen that the pear has a wider circumference toward its bottom, and the apple has the widest circumference towards its center. Of course, these two shapes are the extremes that reside at each end of the shape spectrum. The shape characteristics of the majority of the morbidly obese tend to be in between. The term “mixed shape” is often loosely used to describe these individuals, but all terms heretofore in use today for describing the physical shape of the morbidly obese are qualitative and therefore subject to the eye of the beholder.

It should be noted that the gynecoid shape and the android shape are not gender-specific classifications, though the great majority of morbidly obese gynecoid shapes tend to be female and the great majority of morbidly obese android shapes tend to be male. There certainly are instances where morbidly obese males have a clear “pear-like” shape, and occasions where one encounters a morbidly obese female that possesses a definite “apple-like” shape.

2. Methodology

3D booth-type scanners have been used to document the measurements of preoperative morbidly obese individuals, and to track their measurement changes periodically after weight loss surgery as part of postoperative follow-up visits. These individuals are particularly interested in their initial common circumferential measurements and their subsequent periodic changes.

The measurement software associated with the scanner can also produce multidimensional information such as torso volume and torso surface area. When these are combined with circumferential measurements and heights of certain measurements, mathematical relationships can be formed that produce consistent numerical values across the spectrum of observed morbidly obese shapes. These numerical values are range bound. A scale has been developed to interpret and categorize the physical shape of the morbidly obese individual based on these numerical values.

Key to developing these equations is the use of a “torso slice file” as part of a programmable measurement extraction profile that is applied to the 3D body model acquired by the 3D booth scanner. This is a “canned” algorithm provided by scanner manufacturers and contains routines that slice the torso into segments of 1 cm or 1 inch as determined by the measurement unit selected. This paper used measurements produced in centimeters for the torso slice file data. The “torso slice file” output contains torso segments by height, as determined from the floor of the scanner. Associated with each segment is its surface area and volume.

Figure 3 depicts the application of a measurement profile that includes the “torso slice file” to a 3D body model of a morbidly obese individual. The torso of the individual shown in the figure includes the head. However, the slices of the torso begin at the “Back of Neck” measurement landmark. The head is not included in any of the torso slice measurements.

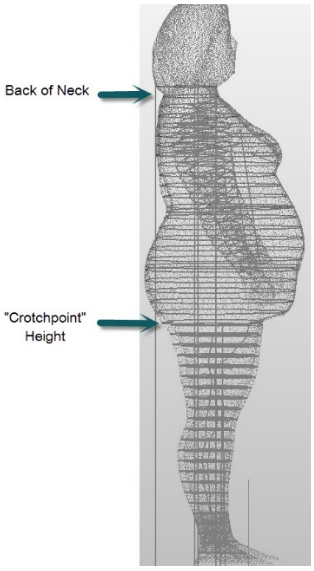
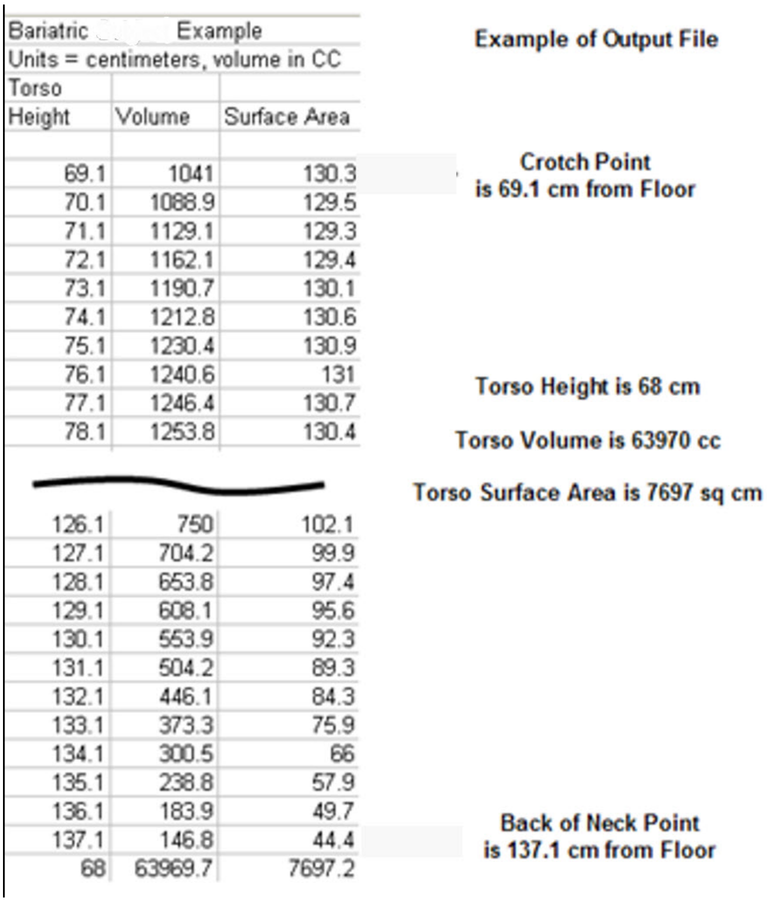


Figure 3. Example of how a Torso is “Sliced” by the Scanner Measurement Software

Figure 4 displays an example of a “torso slice file” output. It is truncated and is for illustrative purposes only. These length of these files are variable, depending on the torso height of the individual.



Bariatric [redacted] Example
Units = centimeters, volume in CC

Torso Height	Volume	Surface Area
69.1	1041	130.3
70.1	1088.9	129.5
71.1	1129.1	129.3
72.1	1162.1	129.4
73.1	1190.7	130.1
74.1	1212.8	130.6
75.1	1230.4	130.9
76.1	1240.6	131
77.1	1246.4	130.7
78.1	1253.8	130.4
126.1	750	102.1
127.1	704.2	99.9
128.1	653.8	97.4
129.1	608.1	95.6
130.1	553.9	92.3
131.1	504.2	89.3
132.1	446.1	84.3
133.1	373.3	75.9
134.1	300.5	66
135.1	238.8	57.9
136.1	183.9	49.7
137.1	146.8	44.4
68	63969.7	7697.2

Example of Output File

Crotch Point is 69.1 cm from Floor

Torso Height is 68 cm

Torso Volume is 63970 cc

Torso Surface Area is 7697 sq cm

Back of Neck Point is 137.1 cm from Floor

Figure 4.Example Output Data from applying the Torso Slice File Algorithm

It is important to note that the torso in this case is defined to include the hips and the buttocks. This is a critical point. The inclusion of the hips and buttocks allows for the determination of the shape of the individual, of which the torso dominates. This definition of the torso also allows it to be a fair proxy for the overall body.

The top of the torso is found by locating the “Back of Neck” landmark and determining its height from the floor. The bottom of the torso is found by locating the “Crotchpoint” landmark and determining its particular height. The difference between these two points comprise the torso height. Care must be taken to verify as to where the scanner measurement software determines the height location of the “Crotchpoint.” This location often has to be manually adjusted.

The reasons for the accurate location of the “Crotchpoint” are two-fold. First, the “Crotchpoint” location has a direct influence on the number of torso slices produced, which in turn affects the torso volume and torso surface area values. If the location is too low, more torso segments will be produced and the torso volume and surface area values will be exaggerated. If the point is too high, less segments will be produced and the torso volume and torso surface area values could be materially understated.

The second reason is that the torso height must be consistent between successive scans for the same individual and as close as possible between all scans in an individual’s sequential series. This allows the multidimensional changes between two scans, or all longitudinal scans to be meaningfully compared. It is not always possible to have EXACT torso height consistency between all scans in a series. In theory, the torso height of an individual should not normally change. However, the author has noted instances where certain individuals experience massive weight loss and their torso height calculation has changed slightly, in either direction. For this reason, the author and this analysis allows up to a 2 cm range of torso height differences to be acceptable across an individual’s sequential scan series.

Inaccurate location of the “Crotchpoint” height point has a greater distortive effect on torso surface volume and torso surface area than an inaccurate location of the “Back of Neck” height point in most circumstances. This is because of the size of circumference of the segments associated with the lower torso of the body. On the other hand, the “Back of Neck” location can be influenced by an individual’s hair. If the hair happens to drape over the neck and onto the shoulders and the torso, the segments produced at the top of the torso will have circumferential measurement distortion. Since the 3D booth scanners use surface scanning technology, hair draped over the neck will be included in the neck circumferential measurement. This may not change the number of torso segments based on where the “Back of Neck” landmark height point is located, but the volume and surface area associated with those segments will be exaggerated to the degree that the individual’s hair overlaps the neck and shoulders. In general, this is prevented by ensuring that the individual has their hair above the back of their neck prior to being scanned.

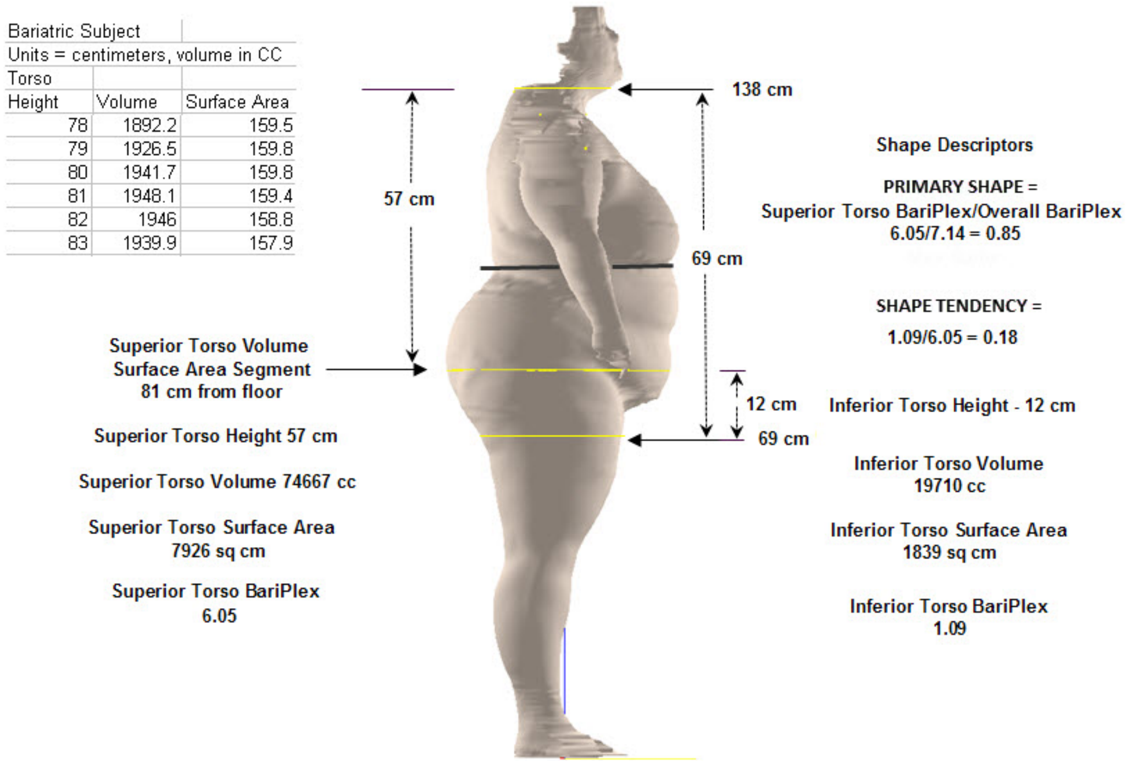
The output of the torso slice file can be utilized in several ways. First, the torso height can be determined, as well as the torso volume and torso surface area by summing up the columns provided by each individual torso segment. This information is used to calculate the BariPlex and Torso Volume/Torso Surface Area Ratio, or TVSA Ratio. An extensive introduction to the BariPlex and TVSA Ratio has been previously published[6].

The BariPlex is a component that is utilized in the shape descriptor equations. The BariPlex is found by dividing the Torso Height by the TVSA Ratio. The result is a dimensionless number that normalizes the TVSA Ratio with the torso height. Since the torso height is range bound in the adult population, the BariPlex can be compared to others with similar torso heights directly, or collectively along a statistically generated curve within the greater population.

The torso slice file output also contains pertinent information that allows the determination of the height of the maximum torso circumference and the median (midpoint) torso circumference, as well as the torso volume and torso surface area above and below the height of these measurements.

This is the information needed to mathematically determine the shape of the morbidly obese body.

Figure 5 depicts key circumferential locations that can be determined by examining the torso slice file output.



Bariatric Subject
Units = centimeters, volume in CC

Torso Height	Volume	Surface Area
78	1892.2	159.5
79	1926.5	159.8
80	1941.7	159.8
81	1948.1	159.4
82	1946	158.8
83	1939.9	157.9

Figure 5.Determining Key Circumferential Torso Segment Heights, Volumes and Surface Areas

One can search the torso slice file output for the Maximum Circumference segment and its height, from the floor. Presumably, this corresponds to the section of the torso where maximum fat distribution is centered.

The “Median Height,” or “Midpoint” of the torso can also be determined by such inspection. This is simply the height of each torso segment comprising the torso height summed, and then divided by two. If the result is not an even number, it is rounded to the next highest integer.

In theory, the maximum torso circumference of a purely gynecoid individual should be centered about the hips. Therefore, one can compare the height of the maximum circumference torso slice to the height of the hips measurement, as determined by the scanner’s measurement software.

In turn, the maximum torso circumference of a purely android individual should be centered around or close to the waist. One can then compare the height of the maximum circumference torso slice to the “Waist_Back_Full” and “Waist_Front_Full” measurement heights, or alternatively, the distance between the maximum torso circumference height and the midpoint torso circumference height.

There are tremendous variations in the size and shapes of the morbidly obese individuals, so simple and straightforward comparisons between the heights of these measurements and the heights of the torso slice measurements can only form the conceptual foundation. Multidimensional information is required to create a full set of meaningful equations.

The multidimensional information we are interested in is the overall torso volume and overall torso surface area, and the portions of the torso volume and surface area above and below the maximum torso circumference height.

There is a fundamental relationship between torso volume and torso surface area when the torso height is fixed. Obese individuals have a greater volume relative to their surface area. Thinner individuals have a greater proportion of surface area relative to their volume. Thus obese individuals have a greater Torso Volume/Torso Surface Area Ratio than thinner counterparts, given a fixed torso height.

Figure 6 illustrates this principle.

Ectomorph
Torso Volume 31860 cc
Torso Surface Area 5391 sq cm
TVSA = 5.91

Endomorph
Torso Volume 55921 cc
Torso Surface Area 7135 sq cm
TVSA = 7.84

Morbidly Obese
Torso Volume 84858 cc
Torso Surface Area 8667 sq cm
TVSA = 9.79

Each Torso Height is 64 cm

Figure 6.Comparison of TVSA Ratio Values for Torsos with Same Torso Height

The individuals in Figure 6 all have the same torso height. The torso that appears most obese has a larger volume relative to its surface area and is reflected in the elevated TVSA Ratio value. The torso in the center is has less volume and less surface area than the morbidly obese torso. Its TVSA Ratio is correspondingly less. The torso that appears to be the thinnest has the lowest TVSA Ratio reading.

Even within the morbidly obese category there are varying degrees of TVSA Ratio values based on body shape and size. This is what differentiates the TVSA Ratio from BMI (Body Mass Index).

Figure 7 displays three torsos of morbidly obese females that have the same torso height but different torso shapes. They also have similar weight and BMI values.

Height 64 in
Weight 304 lbs
BMI 52
Waist 135 cm
Hips 173 cm
W/H Ratio .78
Torso Volume 106591 cc
Torso Surface Area 9958 sq cm
TVSA 10.7

Height 65 in
Weight 300 lbs
BMI 50
Waist 149 cm
Hips 152 cm
W/H Ratio .98
Torso Volume 99852 cc
Torso Surface Area 9713 sq cm
TVSA 10.28

Height 64 in
Weight 300 lbs
BMI 52
Waist 143 cm
Hips 163 cm
W/H Ratio .88
Torso Volume 97880 cc
Torso Surface Area 9815 sq cm
TVSA 9.97

Height 64 in
Weight 290 lbs
BMI 50
Waist 125 cm
Hips 160 cm
W/H Ratio .78
Torso Volume 94377 cc
Torso Surface Area 9765 sq cm
TVSA 9.66

Each Subject has a Torso Height of 69 cm

Figure 7. Morbidly Obese Torsos with Fixed Torso Height can have different TVSA Ratios

As can be seen in from Figure 7, most of these individuals present with a body shape that is clearly in between the classic "Apple" or the classic "Pear."

To determine "Primary Shape" one first finds the BariPlex of the individual. The BariPlex is the torso height divided by the product of (torso volume/torso surface area). This is found by determining the torso height from the torso slice file and summing the associated columns for each height segment volume and surface area.

The next step is to find the height of the maximum circumference torso slice. This, presumably, is where the maximum fat is concentrated about the torso. There are few notable exceptions that will be explained in the Discussion session.

To find the Primary Shape value, one first determines the Superior Torso BariPlex. This is the torso volume and torso surface area from the back of the next point down to the height of the maximum torso circumference segment. The Superior Torso BariPlex is thus equal to Superior Torso Height divided by the product of (Superior Torso Volume / Superior Surface Area) as depicted in Figure 5.

The Primary Shape value is then the Superior Torso BariPlex divided by the (overall) BariPlex. This, in effect acts as a proxy for the weight distribution in the form of volume and surface area above and below the maximum torso circumference height. Figure 8 displays this conceptual calculation.

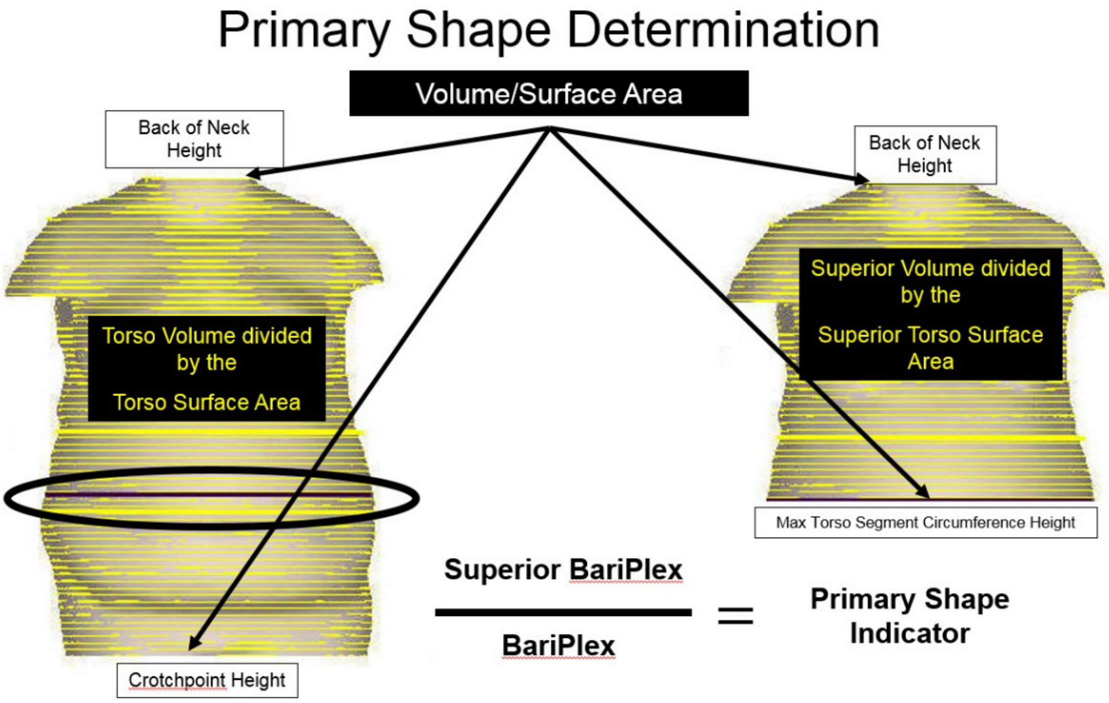


Figure 8.Method for Determining the Primary Shape Indicator

Figure 9 depicts two morbidly obese individuals that displays the characteristics of the gynecoid shape and the android shape. These are the individuals displayed in Figure 1.

The Primary Shape Indicator value for the example gynecoid body shape is 0.85. This reflects that the torso maximum circumference height is towards the hips and most of the torso volume and surface area is above this height. The Primary Shape value for the example android body shape is .65. In this case the maximum torso circumference height is closer to the midpoint of the torso. This indicates that torso volume and torso surface area are somewhat more evenly distributed amongst both halves of the torso.

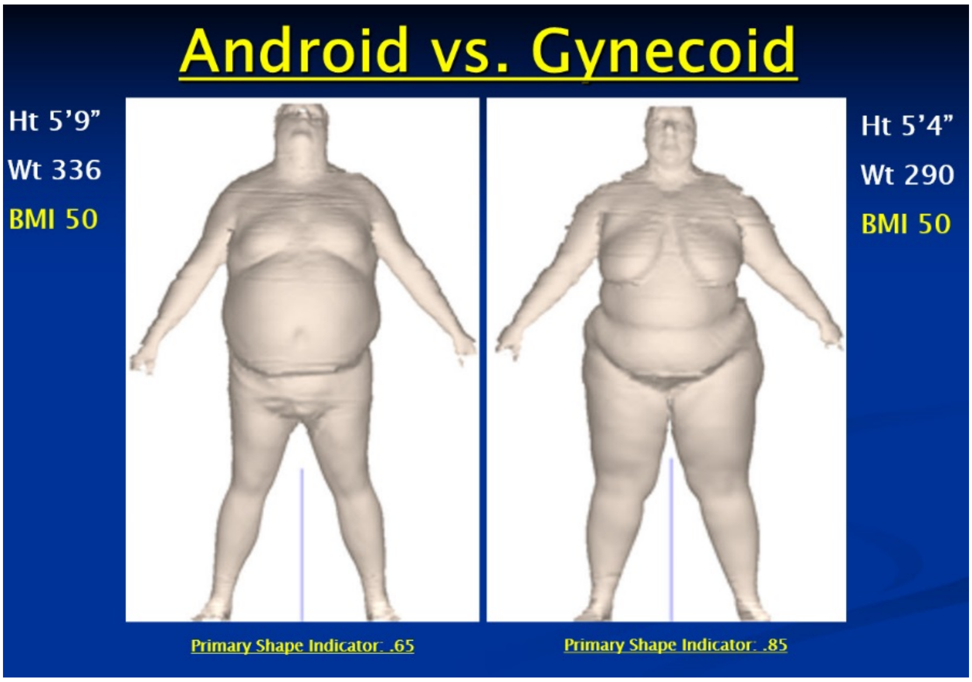
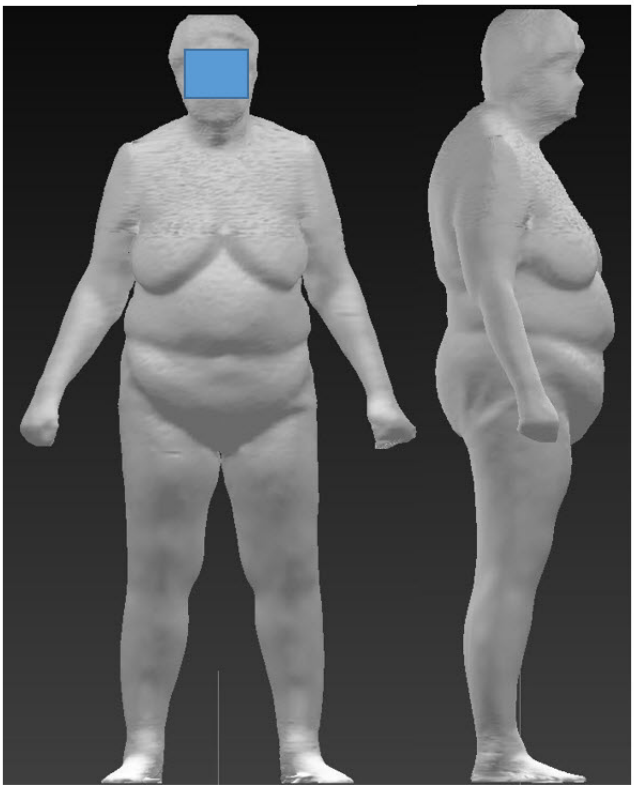


Figure 9.Primary Shape Determination for Android and Gynecoid Morbidly Obese Body Shapes

Figure 10 displays a morbidly obese individual of "mixed" shape. That is, the shape is not clearly "pear-like", nor is it "apple-like". The shape is somewhere in between. This demonstrates the need to use multidimensional information in these calculations since the torso volume and torso surface area together represent a three dimensional outline of the contour of the torso. The Primary Shape value for this individual is .75.

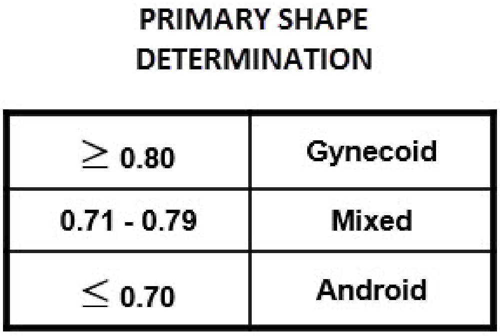


Mixed Shape – Primary Shape Descriptor: .75

Figure 10.Mixed Body Shape Primary Shape Indicator Example

Table 1 displays the Primary Shape Indicator Scale. This range on this scale was determined from a statistical analysis performed on a very large population of morbidly obese individuals that were scanned preoperatively, regardless of gender. However, the cut off points as to what comprised a clear android shape or a clear gynecoid shape were very much influenced by the surgeons' opinions.

It was decided that if an individual had a Primary Shape value of .80 or above, that individual would be considered "gynecoid." If individuals had a Primary Shape value of .70 or below they would be considered "android." In between these body shapes they would be designated as "mixed." For instance, if an individual has a Primary Shape value of .75, they would be have a perfectly "mixed shape." One would then look at their Shape Tendency (discussed below) to determine their "shape direction." Those with a Primary Shape value falling between .71 and .74 tend to be more "android" in appearance, with the individual having a Primary Shape value of .71 on the threshold of being declared an android shape. Those falling between .76 and .79 tend to be more "gynecoid" in appearance.



PRIMARY SHAPE DETERMINATION

$\geq$ 0.80	Gynecoid
0.71 - 0.79	Mixed
$\leq$ 0.70	Android

Table 1. Primary Shape Indicator Scale for Determining Morbidly Obese Body Shape

The Primary Shape indicator, as its name suggests is the overriding component of the Shape Descriptor set. Since this number is range bound across the spectrum of morbidly obese body shapes, it is very common for two body shapes that are similar but certainly not identical to have the same Primary Shape value. Just as it is very common for two individuals of different shapes and sizes to have the same BMI.

For this reason, there is another component of the shape descriptor set that determines the individual's "Shape Tendency."

The Shape Tendency indicates the "intensity" of the shape. It is a secondary indicator and is found by subtracting the Superior Torso BariPlex from the (overall) BariPlex. This determines the Inferior Torso BariPlex. The Shape Tendency is then derived by dividing the Inferior Torso BariPlex into the Superior Torso Bariplex. The result is the "intensity" or "degree" of the Primary Shape. This is depicted in Figure 5 in the lower right corner. The lower the resulting value, the more dominance the Superior Torso Bariplex asserts on the Primary Shape. The Shape Tendency could be considered to be the "first derivative" of the Primary Shape.

Figure 11 shows two such examples of morbidly obese individuals that have the same Primary Shape, but different Shape Tendency values. They are both categorized as "Gynecoid." The individual on the right has a lower shape tendency value, indicating that the Inferior Torso BariPlex, or the torso volume/torso surface area below the maximum torso circumference point divided by the Superior Torso BariPlex is less than her counterpart that has the same Primary Shape categorization. One could declare that she is more "gynecoid" in shape than the other. This allows further differentiation between individuals that have the same Primary Shape indicator. Note that the individuals in Figure 12 have no similarity to each other in terms of height and weight. Comparisons are possible because the Primary Shape and Shape Tendency equations use ratios of volume and surface area along with their associated heights, producing dimensionless numbers.

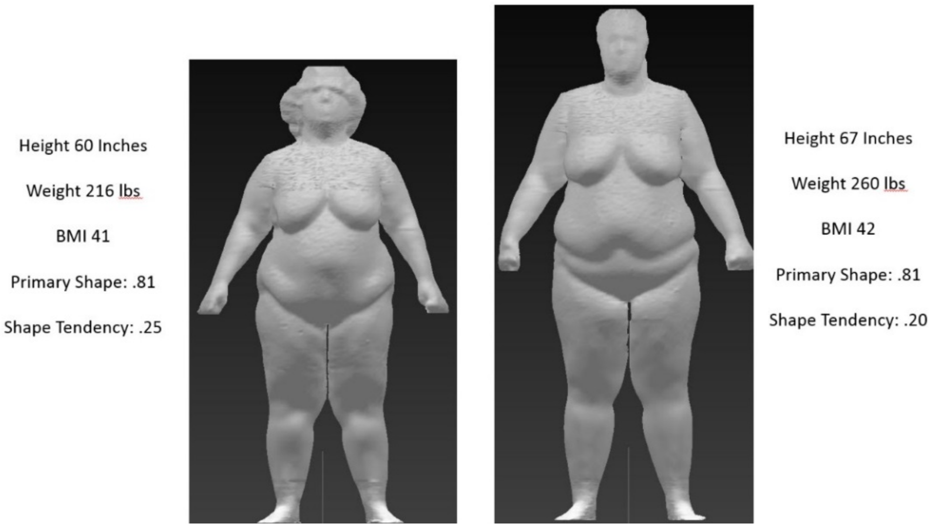


Figure 11. The Shape Tendency Value can differentiate between Identical Primary Shape Values

The complete Shape Descriptor Scale is displayed Table 2.

Primary Shape Indicator Value	**Shape Tendency Value**	**Body Shape**
0.80 or Greater	Lower Value – More Gynecoid	**Gynecoid**
0.71 to 0.79	Higher Value – Tending Android	**Mixed**
0.70 or Lower	Higher Value More Android	**Android**

Table 2. The Complete Shape Descriptor Scale

3. Results

The first purpose for developing the Shape Descriptor Scale was to mathematically quantify the shape of various morbidly obese individuals to help eliminate the “guesswork” visual estimations in practice today. In general, it is well known that individuals possessing an android shape can pose a more difficult surgical challenge than others that have a mixed or gynecoid shape. This mainly has to do with access to the liver, which must be retracted to expose the duodenum.

By ranking the morbidly obese in terms of Primary Shape and Shape Tendency it is possible to give the surgeon a clear shape designation of the morbidly obese individual prior to the surgical procedure, and perhaps anticipate any difficulties that the individual’s shape may portend.

As more and more individuals came back for their follow up visits and postoperative scans, a wealth of longitudinal information began to accumulate. The postoperative individuals typical lose the most weight within their first 3 months after gastric bypass or gastric sleeve surgery, and their circumferential measurements, torso volume and torso surface area measurements are commensurately lower. The weight loss tends to be less as time progresses, but it is still significant and their changes in all measurements reflect this…except the Shape Descriptors.

It was noticed that their Shape Descriptors, for the most part, did not change significantly as they underwent massive weight loss! This was quite a remarkable finding.

Table 3 displays a longitudinal spreadsheet that is typical of how individuals are measured and tracked before and after their weight loss surgery. All measurements, with the exception of the weight recording are provided by the 3D booth scanner.

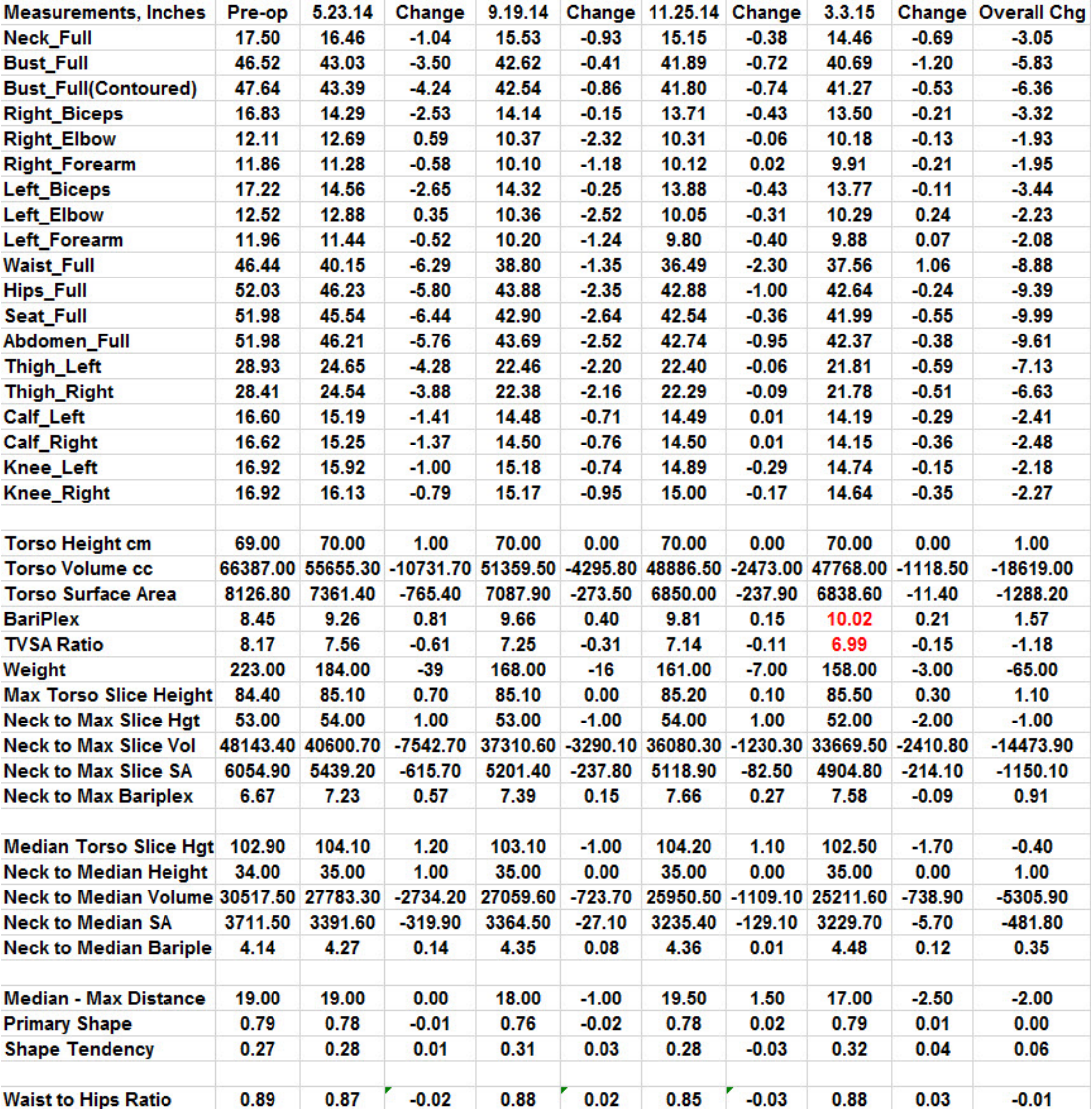
The spreadsheet documents their preoperative circumferential measurements, multidimensional measurements and their Shape Descriptors. Each dated column reflects the postoperative measurements of the scan taken that day, and the recorded weight. The “Change” columns indicate the sequential change between scan periods. The “Overall Chg” column summarizes the changes between the preoperative scan measurements and measurements created by the last scan in the sequence.

The top part of this table displays circumferential measurement changes between successive scans and between the preoperative scan and the 1 year postoperative scan. At present, this is the measurement information that most individuals who have undergone weight loss surgery wish to review.

The center part of the spreadsheet contains multidimensional information and the height of particular circumferential measurements as found by manipulating the data within each torso slice file output. By finding the torso height, torso volume and torso surface area one can calculate the BariPlex and the TVSA Ratio.

Here is where it is critical to ensure that the torso height is as consistent as possible between sequential scans and over the entire scan series. This example has torso heights within the 2 cm band the author considers to be a requirement for meaningful longitudinal comparisons. As mentioned earlier, it is not uncommon to have to manually adjust the crotch point location to ensure such consistency.

One can also observe the individual’s initial weight and subsequent weight as recorded at the time of each postoperative scan.



Measurements, Inches	Pre-op	5.23.14	Change	9.19.14	Change	11.25.14	Change	3.3.15	Change	Overall Chg
Neck_Full	17.50	16.46	-1.04	15.53	-0.93	15.15	-0.38	14.46	-0.69	-3.05
Bust_Full	46.52	43.03	-3.50	42.62	-0.41	41.89	-0.72	40.69	-1.20	-5.83
Bust_Full(Contoured)	47.64	43.39	-4.24	42.54	-0.86	41.80	-0.74	41.27	-0.53	-6.36
Right_Biceps	16.83	14.29	-2.53	14.14	-0.15	13.71	-0.43	13.50	-0.21	-3.32
Right_Elbow	12.11	12.69	0.59	10.37	-2.32	10.31	-0.06	10.18	-0.13	-1.93
Right_Forearm	11.86	11.28	-0.58	10.10	-1.18	10.12	0.02	9.91	-0.21	-1.95
Left_Biceps	17.22	14.56	-2.65	14.32	-0.25	13.88	-0.43	13.77	-0.11	-3.44
Left_Elbow	12.52	12.88	0.35	10.36	-2.52	10.05	-0.31	10.29	0.24	-2.23
Left_Forearm	11.96	11.44	-0.52	10.20	-1.24	9.80	-0.40	9.88	0.07	-2.08
Waist_Full	46.44	40.15	-6.29	38.80	-1.35	36.49	-2.30	37.56	1.06	-8.88
Hips_Full	52.03	46.23	-5.80	43.88	-2.35	42.88	-1.00	42.64	-0.24	-9.39
Seat_Full	51.98	45.54	-6.44	42.90	-2.64	42.54	-0.36	41.99	-0.55	-9.99
Abdomen_Full	51.98	46.21	-5.76	43.69	-2.52	42.74	-0.95	42.37	-0.38	-9.61
Thigh_Left	28.93	24.65	-4.28	22.46	-2.20	22.40	-0.06	21.81	-0.59	-7.13
Thigh_Right	28.41	24.54	-3.88	22.38	-2.16	22.29	-0.09	21.78	-0.51	-6.63
Calf_Left	16.60	15.19	-1.41	14.48	-0.71	14.49	0.01	14.19	-0.29	-2.41
Calf_Right	16.62	15.25	-1.37	14.50	-0.76	14.50	0.01	14.15	-0.36	-2.48
Knee_Left	16.92	15.92	-1.00	15.18	-0.74	14.89	-0.29	14.74	-0.15	-2.18
Knee_Right	16.92	16.13	-0.79	15.17	-0.95	15.00	-0.17	14.64	-0.35	-2.27
Torso Height cm	69.00	70.00	1.00	70.00	0.00	70.00	0.00	70.00	0.00	1.00
Torso Volume cc	66387.00	55655.30	-10731.70	51359.50	-4295.80	48886.50	-2473.00	47768.00	-1118.50	-18619.00
Torso Surface Area	8126.80	7361.40	-765.40	7087.90	-273.50	6850.00	-237.90	6838.60	-11.40	-1288.20
BariPlex	8.45	9.26	0.81	9.66	0.40	9.81	0.15	10.02	0.21	1.57
TVSA Ratio	8.17	7.56	-0.61	7.25	-0.31	7.14	-0.11	6.99	-0.15	-1.18
Weight	223.00	184.00	-39	168.00	-16	161.00	-7.00	158.00	-3.00	-65.00
Max Torso Slice Height	84.40	85.10	0.70	85.10	0.00	85.20	0.10	85.50	0.30	1.10
Neck to Max Slice Hgt	53.00	54.00	1.00	53.00	-1.00	54.00	1.00	52.00	-2.00	-1.00
Neck to Max Slice Vol	48143.40	40600.70	-7542.70	37310.60	-3290.10	36080.30	-1230.30	33669.50	-2410.80	-14473.90
Neck to Max Slice SA	6054.90	5439.20	-615.70	5201.40	-237.80	5118.90	-82.50	4904.80	-214.10	-1150.10
Neck to Max Bariplex	6.67	7.23	0.57	7.39	0.15	7.66	0.27	7.58	-0.09	0.91
Median Torso Slice Hgt	102.90	104.10	1.20	103.10	-1.00	104.20	1.10	102.50	-1.70	-0.40
Neck to Median Height	34.00	35.00	1.00	35.00	0.00	35.00	0.00	35.00	0.00	1.00
Neck to Median Volume	30517.50	27783.30	-2734.20	27059.60	-723.70	25950.50	-1109.10	25211.60	-738.90	-5305.90
Neck to Median SA	3711.50	3391.60	-319.90	3364.50	-27.10	3235.40	-129.10	3229.70	-5.70	-481.80
Neck to Median Bariple	4.14	4.27	0.14	4.35	0.08	4.36	0.01	4.48	0.12	0.35
Median - Max Distance	19.00	19.00	0.00	18.00	-1.00	19.50	1.50	17.00	-2.50	-2.00
Primary Shape	0.79	0.78	-0.01	0.76	-0.02	0.78	0.02	0.79	0.01	0.00
Shape Tendency	0.27	0.28	0.01	0.31	0.03	0.28	-0.03	0.32	0.04	0.06
Waist to Hips Ratio	0.89	0.87	-0.02	0.88	0.02	0.85	-0.03	0.88	0.03	-0.01

Table 3. Example of a Longitudinal Spreadsheet used to Document Body Measurements undergoing Massive Weight Loss

Below the “Weight” recording row are the components that make up the data points that are used to calculate the Shape Descriptors. These essentially are the Superior and Inferior BariPlex values above or below the Maximum Torso Circumference Height, and the Upper and Lower Bariplex values above or below the Median Torso Circumference Height.

Another row indicates the individual’s distance between their Median Torso Circumference Height and their Maximum Torso Circumference Height.

The Primary Shape and Shape Tendency rows follow. Finally, a column that calculates “Waist to Hips” Ratio is noted.

A glance longitudinally over the Primary Shape and Shape Tendency rows indicate the consistency of these values as the subject undergoes massive weight loss. Interestingly, the “Waist to Hips” Ratio was consistent across the massive weight loss period as well.

The individual’s initial Primary Shape was nearly gynecoid (.79) and the Primary Shape after losing 65 pounds remained nearly gynecoid (.79). The Shape Tendency indicates that the individual’s shape to be slightly less “gynecoid” at the end of the weight loss period.

Figure 12 depicts the side view of the individual at each scan date. Successive postoperative scans are superimposed on the preoperative scan image.

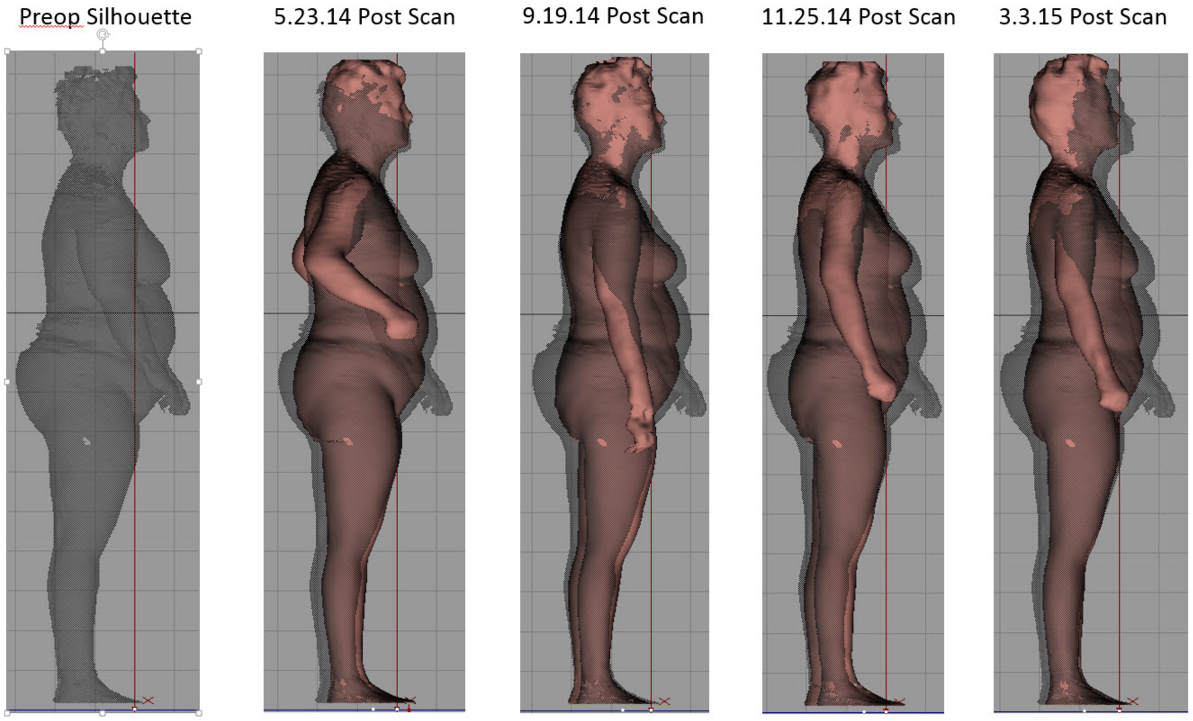


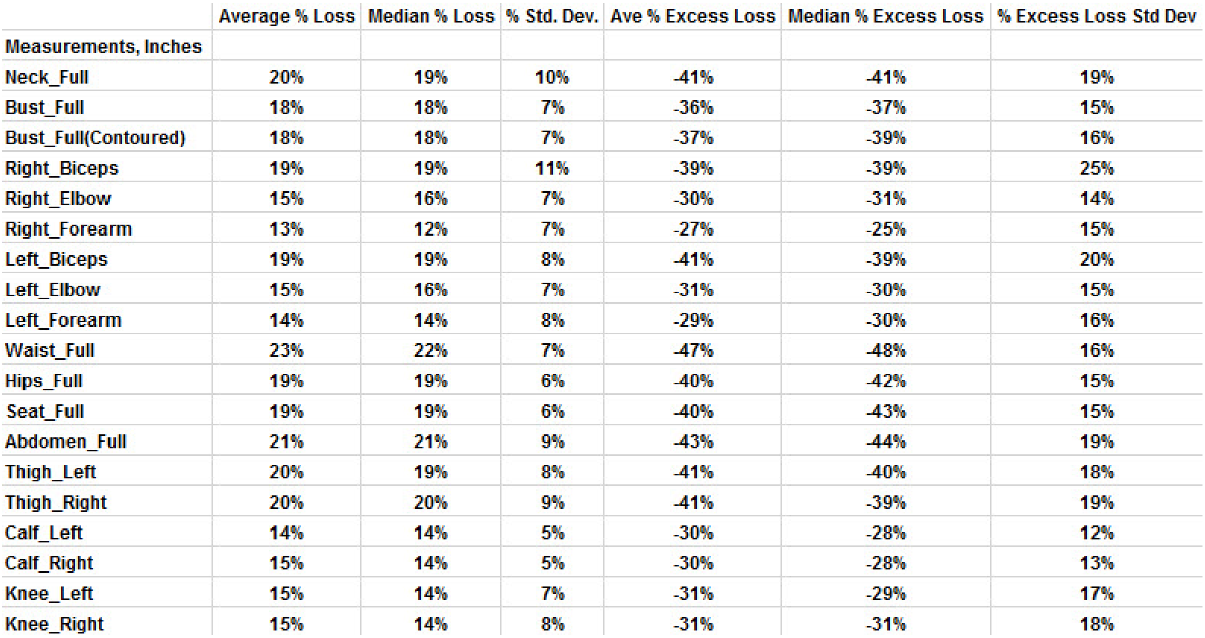
Figure 12. Superimposition of Success Scans within Preoperative Silhoutte

One can visualize the changes to the individual’s body undergoing massive weight loss. The measurement numbers within the spreadsheet corroborate this. What is not immediately evident is that the Shape Descriptors remain consistent over the weight loss period.

This finding can be combined with statistical weight loss averages and associated circumference, volume and surface areas changes at the end of a 1 year period after weight loss surgery to create a predictive weight loss model of a preoperative morbidly obese individual.

A statistical analysis of such aggregated, de-identified longitudinal data has been presented in another paper[5].

The summary of those statistics are in the Table 4. The paper in the reference describes in detail the basis and premise of how the statistics were developed.



	Average % Loss	Median % Loss	% Std. Dev.	Ave % Excess Loss	Median % Excess Loss	% Excess Loss Std Dev
Measurements, Inches						
Neck_Full	20%	19%	10%	-41%	-41%	19%
Bust_Full	18%	18%	7%	-36%	-37%	15%
Bust_Full(Contoured)	18%	18%	7%	-37%	-39%	16%
Right_Biceps	19%	19%	11%	-39%	-39%	25%
Right_Elbow	15%	16%	7%	-30%	-31%	14%
Right_Forearm	13%	12%	7%	-27%	-25%	15%
Left_Biceps	19%	19%	8%	-41%	-39%	20%
Left_Elbow	15%	16%	7%	-31%	-30%	15%
Left_Forearm	14%	14%	8%	-29%	-30%	16%
Waist_Full	23%	22%	7%	-47%	-48%	16%
Hips_Full	19%	19%	6%	-40%	-42%	15%
Seat_Full	19%	19%	6%	-40%	-43%	15%
Abdomen_Full	21%	21%	9%	-43%	-44%	19%
Thigh_Left	20%	19%	8%	-41%	-40%	18%
Thigh_Right	20%	20%	9%	-41%	-39%	19%
Calf_Left	14%	14%	5%	-30%	-28%	12%
Calf_Right	15%	14%	5%	-30%	-28%	13%
Knee_Left	15%	14%	7%	-31%	-29%	17%
Knee_Right	15%	14%	8%	-31%	-31%	18%

	%Excess Weight Loss	% Excess Torso Volume Loss	% Excess Torso Surface Area Loss	% Excess BariPlex GAIN	% Excess TVSA Ratio Loss
Average	**.70**	**-0.74**	**-0.40**	**0.55**	**-0.42**
Median	.71	-0.72	-0.40	0.48	-0.42
Std. Dev	.16	0.09	0.11	0.22	0.14
MIN	.43	-0.52	-0.65	0.16	-0.78
MAX	1.01	-0.16	-0.22	1.26	-0.13

Table 4. Statistical Measurement Loss Averages 1 Year after Weight Loss Surgery for a Group of 50 Females

Table 5 used these 1 year postoperative statistics and the initial measurement parameters of the individual to estimate what the individual's measurements might be after the subject nears the expected 75% "Excess Weight Loss" to be achieved around 1 year after weight loss surgery. The 75% "Excess Weight Loss" is one criteria to determine a successful outcome for weight loss surgery.

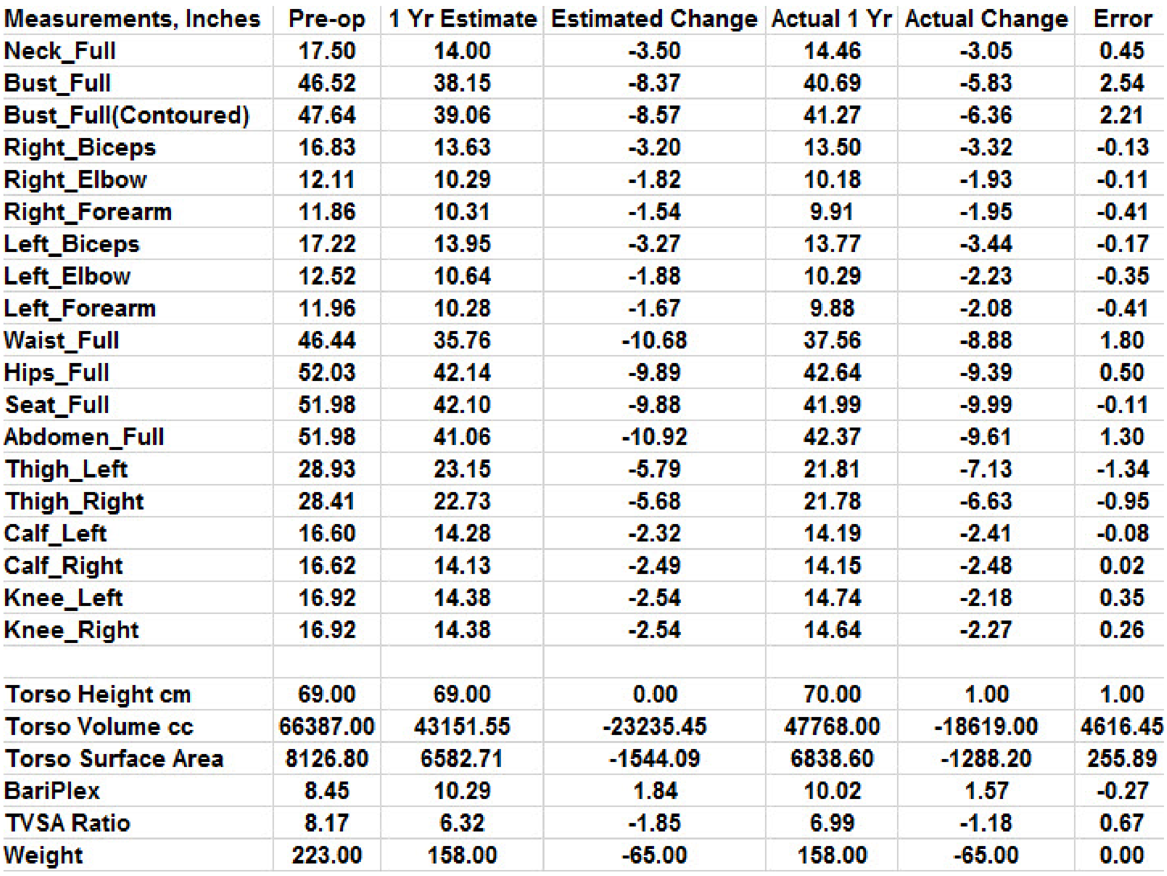
It should be noted that the numbers in the "Average Weight Loss" column in Table 2 were used as multipliers for this example.

Also included in this Table 5 are the individual's actual measurements 1 year after weight loss surgery determined by the 1 year postoperative scan, and an "estimation error" between the predicted measurements and the actual measurements.

The weight of the individual is recorded prior to surgery. The estimated weight at the end of the 1 year period was found using reference weight tables as per standard practice. In this particular case the individual was female and her height was 65 inches. The reference weight for her height is 137 pounds. Therefore she is "overweight" by 86 pounds. To achieve 75% "Excess Weight Loss" the individual needs to lose 65 pounds. This is shown in the "Weight" entry row intersecting with the "Estimated Change" column.

In actuality, this individual did lose exactly 75% of her Excess Weight one year of surgery.

Of course, each individual is different and will lose weight at a faster or slower pace. Some may not reach the goal of 75% "Excess Weight Loss." This could be for a number of reasons, ranging from a medical condition, or a particular medicinal regime to not adopting the lifestyle changes required to meet the weight loss goal and maintain a healthy weight. Some may also exceed this goal and lose up to 100% or more of their "Excess Weight."



Measurements, Inches	Pre-op	1 Yr Estimate	Estimated Change	Actual 1 Yr	Actual Change	Error
Neck_Full	17.50	14.00	-3.50	14.46	-3.05	0.45
Bust_Full	46.52	38.15	-8.37	40.69	-5.83	2.54
Bust_Full(Contoured)	47.64	39.06	-8.57	41.27	-6.36	2.21
Right_Biceps	16.83	13.63	-3.20	13.50	-3.32	-0.13
Right_Elbow	12.11	10.29	-1.82	10.18	-1.93	-0.11
Right_Forearm	11.86	10.31	-1.54	9.91	-1.95	-0.41
Left_Biceps	17.22	13.95	-3.27	13.77	-3.44	-0.17
Left_Elbow	12.52	10.64	-1.88	10.29	-2.23	-0.35
Left_Forearm	11.96	10.28	-1.67	9.88	-2.08	-0.41
Waist_Full	46.44	35.76	-10.68	37.56	-8.88	1.80
Hips_Full	52.03	42.14	-9.89	42.64	-9.39	0.50
Seat_Full	51.98	42.10	-9.88	41.99	-9.99	-0.11
Abdomen_Full	51.98	41.06	-10.92	42.37	-9.61	1.30
Thigh_Left	28.93	23.15	-5.79	21.81	-7.13	-1.34
Thigh_Right	28.41	22.73	-5.68	21.78	-6.63	-0.95
Calf_Left	16.60	14.28	-2.32	14.19	-2.41	-0.08
Calf_Right	16.62	14.13	-2.49	14.15	-2.48	0.02
Knee_Left	16.92	14.38	-2.54	14.74	-2.18	0.35
Knee_Right	16.92	14.38	-2.54	14.64	-2.27	0.26
Torso Height cm	69.00	69.00	0.00	70.00	1.00	1.00
Torso Volume cc	66387.00	43151.55	-23235.45	47768.00	-18619.00	4616.45
Torso Surface Area	8126.80	6582.71	-1544.09	6838.60	-1288.20	255.89
BariPlex	8.45	10.29	1.84	10.02	1.57	-0.27
TVSA Ratio	8.17	6.32	-1.85	6.99	-1.18	0.67
Weight	223.00	158.00	-65.00	158.00	-65.00	0.00

Table 5. Comparison between Estimated 1 Year Measurement Change vs. Actual 1 year Changes

The 1 year estimates for measurements were found by multiplying the initial measurements by the appropriate (1 - "Average % Loss") for each measurement in the statistical analysis, with the exception of the BariPlex and TVSA Ratios. Since these are already ratios themselves the estimated changes for the Bariplex and TVSA were found by adding the Overall Bariplex change and Overall TVSA Ratio change to their respective initial values.

The 1 year estimated measurements are remarkably consistent with the 1 year actual measurements. The notable exception here are the bust measurements and perhaps the waist and abdomen measurements.

Note that the estimated measurements were created from a broad set of 50 female individuals who underwent weight loss surgery and were scanned periodically out to 1 year. That set consisted of individuals who weighed as much as 470 pounds and height as great as 70 inches. Further refinement of this technique will be possible when the population set produces enough longitudinal data that it can be segregated into categories defined by initial height and weight ranges.

4. Discussion

The Shape Descriptors were initially constructed to give some mathematical order to determining the physical shape of the morbidly obese. This was in an effort to help surgeons sort through challenges with potential surgical cases.

As the amount of longitudinal data began to accumulate, it was discovered that these Shape Descriptors remained relative stable for the great majority of samples as the individual underwent massive weight loss. This surprising discovery, coupled with a statistical analysis of circumferential measurements and volume and surface area changes after massive weight loss at the 1 year interval combine to produce a technique that estimates how a preoperative morbidly obese individual's body may appear if they achieve their expected weight loss goal.

There are two ways to produce a predictive weight loss model. One way is to use the individual's initial measurements and export the 3D body model to a CAD data modeling program. Once in the CAD modeling program, the body model can be volumetrically scaled to the predictive torso volume loss at 1 year estimate while holding the Y-axis is fixed. This will reduce the volume along the X and Z axis, as the Y axis, or the height is constrained. The reduction in estimated torso volume loss acts as a reasonable proxy for total body volume loss. This is a simple and crude approach. It does not necessarily result in a body model that can be converted back into scanner 3D format to determining specific estimated circumferential measurement changes, but it is very useful to the individual as it produces a predictive model that can be superimposed within the preoperative image outline. The estimated predictive measurements would be tabulated separately, as in Table 5, and presented with this superimposed image to the preoperative individual.

Successive postoperative scan measurement information would be iterated and an updated predictive 1 year weight loss model would be developed after each scan leading up to the 1 year interval.

The other method is to reverse the process of creating a body model. Instead of scanning an individual and producing measurement results, the predictive measurement outcomes would be entered and a resultant body model produced. It would need to be based on the some measurements not normally recorded, such as the length of the arms and the length of the legs. These types of measurements, like torso height, would presumably not change significantly from scan to scan as the individual loses weight.

It has been noted that the Shape Descriptors remain relatively constant during an individual's weight loss. This is in general true provided that the torso height remains consistent throughout the sequential scanning sequence. There have been exceptions to this.

There have been certain cases where the torso height has remained consistent throughout the scan series, but the Shape Descriptors of the individual have changed significantly over the course of their weight loss.

This has to do with the distance between the maximum torso circumference height and the median torso circumference height changing value between scan intervals. This "Mid-Max" value influences the Superior and Inferior BariPlex calculations, even if the torso height between the two scans are the same. This would change the Shape Descriptor values. It does not happen very often, but it has been noted. For the "Mid-Max" torso height difference to change significantly, the torso must be undergoing some sort of uncommon change not associated with typical uniform weight loss. For example, if an individual that had an extended stomach suddenly loses dramatic circumference relative to other circumferences within the torso, the Mid-Max height difference would change significantly. Another example of an abnormal, dramatic change would be an individual having an abdominoplasty (AKA "Tummy Tuck"), or circumferential pannulectomy cosmetic surgery procedure in between scan intervals.

The other exception noted is for morbidly obese males that are "barrel chested", or morbidly obese females that have large chest circumferences relative to their waist and hips. When these situations are encountered, the maximum torso circumference height could be above the torso midpoint height resulting in an invalid Primary Shape value.

This situation has been corrected in the algorithm that searches the torso slice file. If such a situation occurs, the algorithm disregards any maximum torso circumference above the torso height midpoint and selects any slice below this height that has the greatest circumference. When this is done, the Primary Shape value is consistent with other morbidly obese body shapes. This situation is not often encountered, but the effort was made to overcome this condition in order to make the Shape Descriptors calculations consistent over the wide universe of morbidly obese body shapes.

These appear to be the exceptions. Provided that the torso height is generally consistent between successive scans and the sequential scan series, and the individual's hair does not distort any torso volume and torso surface areas segments about the neck area, the Shape Descriptors appear to remain fixed as the individual undergoes massive weight loss.

It should also be noted that the statistical averages were calculated for a set of female individuals only. The statistical averages for males have not been calculated as of yet, though the data is available. The male measurement averages 1 year post weight loss surgery will undoubtedly differ from the female statistics, but the approach to constructing a predictive weight loss model will be the same.

The Shape Descriptors are not gender specific, and in general remain consistent between longitudinal scans for both females and males.

It should also be noted that the group of females from which the statistical data were derived underwent only a gastric bypass or a gastric sleeve procedure.

The ability to create a statistically generated, fairly accurate predictive model of expected body appearance after massive weight loss prior to the surgical procedure is appealing on a number of fronts. First, it acts as motivational aid to the preoperative morbidly obese individual, who can begin to identify with anticipated body changes as a part of the benefits resulting from weight loss surgery.

It also offers new tools and opens new avenues for the important research areas of Body Image Assessment and Body Image Dissatisfaction.

Studies can be generated that query the morbidly obese preoperative individual’s perception of their body by using their preoperative printout and associated circumferential measurements. Their predictive weight loss model and estimated measurements would then be given to them for further investigation. Postoperative scans and measurement updates would yield tangible information to help them understand the physical changes their body is undergoing as they experience massive weight loss. All stages of this could form the basis of new research material, personalized expressly to and for the individual.

Of course, the reverse is also true. One can use this capability and technique to show what an individual’s physical body appearance might look like if they begin to become obese and then eventually morbidly obese.

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