ESTIMATION OF DENSITY OF LIVE PIGS BY AIR DISPLACEMENT AND HELIUM DILUTION PROCEDURES

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ABSTRACT

ESTIMATION OF DENSITY OF LIVE PIGS BY AIR DISPLACEMENT AND HELIUM DILUTION PROCEDURES

By Richard Henry Gnaedinger

The densities of 24 market weight pigs (181-220 lbs.) were determined using the air displacement and helium dilution methods of measuring body volume. The densities thus obtained were correlated with the water, ether extract, protein, and ash content of the live animals in an attempt to objectively predict body composition.

The air displacement method consisted of enclosing the animals in an air tight chamber of known volume and subjecting it to a known reduction in pressure. Body volume was then computed from the resultant pressure-volume relationships according to the gas laws of Boyle and Charles. The densities obtained by air displacement ranged from 0.975 to 1.222 with a mean of 1.075. The major difficulties involved in the air displacement method appeared to be the lack of control of temperature and relative humidity. Of these two variables, relative humidity appeared to have the greater influence on the results. The activity of the animals in the chamber undoubtedly influenced the results somewhat, but the magnitude of this effect could not be ascertained.

The helium dilution method consisted of enclosing the animal in a chamber and injecting and mixing a known quantity of helium in the air space around the animal. The resultant helium concentration in the chamber was proportional to body volume. Helium concentration was ascertained using the thermal conductivity principle for gas analysis. The density

values obtained by helium dilution ranged from 0.940 to 1.114 with a mean of 1.017. The inaccuracies involved in the helium dilution method were caused by the activity of the experimental animals inside the chamber. Changes in temperature, relative humidity, and the composition of the respiratory gases due to the animal's respiration were the major sources of error. Carbon dioxide accumulation and oxygen depletion were detected by the helium analyzer and the effect was superimposed on the helium concentration curve. Thermal expansion of the air-helium mixture and the expiration of the animal resulted in a loss of some helium from the chamber. An expedient correction can be made for these sources of error, if all the variables remain constant or if they change at a constant rate during the course of a run. However, the animals in this study exhibited various degrees of activity, and thus caused fluctuations in the variables during a run.

The density values obtained by both air displacement and helium dilution were correlated non-significantly with percent carcass water, ether extract, protein, and ash. The density values obtained by air displacement were correlated non-significantly with those obtained by helium dilution. Although neither method of measuring body volume was reliable, the helium dilution technique was more predictive of body composition than the air displacement technique.

The average chemical composition of the live pigs used in this study was: 49.03% water (42.11 to 53.17%), 33.00% ether extract (27.37 to 41.13%), 13.69% protein (12.44 to 14.57%), and 2.72% ash (2.20 to 3.12%). The results of the chemical analysis showed that the dressed carcass contained 74.08% of the water, 89.79% of the ether extract, 76.13% of the

protein, and 79.11% of the ash in the whole animal. The carcass, empty intestines, caul fat, and head combined contained 98.77% of the total ether extract in the whole animal. The carcass and head combined contributed 93.50% of the total ash content of the animal. The results of the chemical analysis also suggested that average values for the composition of the hair and blood could be used without introducing any appreciable error in the analysis of the total animal.

The relationship between percent ether extract of the carcasses and of the empty bodies for this group of animals was $r = 0.991$. The regression equation for estimating percent ether extract of the empty body from total body water was: $\hat{Y} = 97.16 - 1.298X$ ($S_{X \cdot y} = \pm 0.52\%$, $r = -0.971$). The relationship between the percentages of water and ether extract in the empty bodies was computed according to the equation: $\hat{Y} = 96.40 - 1.297X$ ($S_{X \cdot y} = \pm 1.5\%$, $r = -0.974$) where X = percent water in the empty body.

A highly significant relationship was found between the percent ether extract of the empty body and the percent water of the ether extract-free empty body ($r = -0.597$). The significance of this relationship suggested that the group of animals used in this study was not chemically mature, and that body fat could not be validly predicted from the water content of the fat-free body.

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INTRODUCTION

Application of Archimede's Principle to Studies on Body Composition

The composition of an animal body during any time in life is a subject of great interest to research workers in the field of animal biology. An objective method of accurately predicting the composition of a live animal has been sought for a long time. To date the only accurate measure of composition, namely chemical analysis, requires that the animal be sacrificed. If an objective measure with this degree of accuracy could be obtained without sacrificing the animal, its potentialities would be great. For instance, the composition of animal gains at any time during growth and development could be measured. Also, its medical applications would be of equal value. The composition of the human body could be followed during conditions such as growth, exercise, starvation, and disease.

Archimedes (287-212 B.C.) observed that the composition of an object could be ascertained by determining its specific gravity. He deduced that a body immersed in a fluid is buoyed up with a force equal to the weight of the displaced fluid (1). Thus, the principle of hydrostatics can be used to characterize various solid objects as to their volume, density, and specific gravity. The volume of an object can be determined directly by immersing it in a fluid and measuring the volume of fluid that it displaces. Its density is determined from the ratio of its mass to volume, and its specific gravity is then computed from the ratio of its density to the density of water.

Archimedes' principle is theoretically equally applicable to the characterization of animate as well as inert objects. For animate objects,

namely live animals, the property of most importance is density, since body composition can theoretically be predicted from the relative value of this property. This is made possible by considering the animal body to be composed of an invariable component of density greater than unity and a variable component of density less than unity. Thus, as the percentage of the variable component, namely fat, increases or decreases, a corresponding inverse relationship exists in the value of the animal's density.

Experimental Objectives

As was previously stated, the volume of an object can be determined directly by measuring the volume of fluid that it displaces. Similarly, volume can be determined by measuring the volume of the gas that it displaces. Hence, the first and most important objective of this study involved the measurement of the volume of gas displaced by live hogs using two methods of measurement, air displacement and helium dilution. The second objective was to establish the relationship between body composition and density for a group of hogs. The third objective was to evaluate each method for its accuracy and precision for measuring body volume and predicting body composition.

REVIEW OF LITERATURE

Determination of Volume by Air Displacement.

The measurement of body volume by air displacement apparently had its beginning some 80 years ago when Jaeger (2, 3) suggested a relationship between corporeal density and health. He attempted to measure the volume of an object by enclosing it in an air tight chamber, which he called a Kopp Volumeter. This chamber was constructed in such a way so that its volume could be changed by a known amount. Then, with an object of unknown volume (V_o) placed inside the chamber of initial volume (V) at atmospheric pressure (P) and V changed to ($V - \Delta V$), V_o was computed from the resultant pressure change (ΔV) with the following equation:

$$V_o = (V - \Delta V) \frac{VP}{(P + \Delta P)} \qquad (1)$$

This procedure was reported as being accurate for determining the volume of inert objects, but complications would result with live animals due to their respiratory exchanges and the increasing air temperature. Inspection of equation 1 reveals that it could not be used to compute the volume of live animals accurately, because it contains no factors to compensate for these inherent variables.

Some 20 years after Jaeger's work, Pfaundler (4) attempted to measure the net volume of a child cadaver, which he defined as the total body volume minus the volume of gas in the respiratory and digestive tracts. He constructed a felt-insulated, brass chamber, 25 cm. wide and 55 cm. long, which was sealed at one end and contained a removable door at the other. A thermometer was used to record the temperature of the air in the chamber, and a sulfuric acid manometer, which could be read

to ± 0.1 mm., was used to record pressure. The procedure for determining volume consisted of changing the pressure of the air inside the chamber by a known amount without altering the actual volume of the chamber itself. Net volume was then taken as an average of two determinations, one being made at a pressure greater than atmospheric and the other at a pressure less than atmospheric. This entire procedure was repeated several times until constant readings were obtained. From 16 observations made on the volume of a cadaver by this method, an average value of 1.143 was obtained for its density. The major disadvantage with this procedure was the great length of time that was required to establish thermal equilibrium between the cadaver and air after each pressure change. The time required to make one reading was about 1.5 hours. During the procedure of making a reading, temperature differences up to 1°C were observed but were regarded as insignificant. However, an error of this magnitude, when made at a temperature of 25°C, will change the computed volume of a 50 liter object by about 4%.

Murlin and Hoobler (5) reported the use of Pfaundler's procedure to determine the density of subjects in a study on the energy metabolism of normal and marasmic children. Their results are tabulated below. The results of this study showed that weight was more closely related to metabolism than was surface area. The relationship was even better when weight was multiplied by density.

Density of children as determined by air displacement

Subject	Age	Weight gms.	Density
Normal boy	2 mo.	5690	0.973
Normal boy	2 mo.	4634	1.034
Normal boy	2 mo.	4350	1.003
Undernourished boy	3 mo.	4115	1.006
Undernourished boy	3 mo.	4147	1.005
Atrophic boy	3 mo.	2462	1.108
Atrophic boy	3 mo.	2515	1.118
Normal girl	10.5 mo.	9465	1.026
Normal boy	12 mo.	9555	1.029

Pfleiderer (6) determined volume with an apparatus consisting of two interconnected chambers, one large enough to hold the subject and the other of suitable size to be used as a standard for altering the pressure of the air inside the subject chamber. Pressures greater than atmospheric were used in his procedure, and the amount of compression was controlled by filling the standard chamber with water, thereby forcing its air into the other chamber. The resultant pressure rise due to the introduction of the air was then directly proportional to the size of the object placed inside the subject chamber. Thus, the difference between the pressures obtained with an empty and an occupied chamber was then used to compute the volume of the subject. With this procedure, Pfleiderer was able to compute body volumes with a mean error of 1 to 2%.

Pfleiderer (6) enumerated a number of precautions that must be observed when determining the volume of live animals. The vapor pressure of water had an effect on the final pressure of the chamber. He attempted to minimize this effect in his procedure by keeping the air saturated at all times. Respiration by the animal effected a gradual change on the final pressure due to the changing partial pressures of the respiratory

gases. This degree of change was in turn dependent on the basal metabolism of the animal. He also observed that a pressure of 200 mm. of water was easily tolerated by live animals. Consequently, he noted that if higher pressures could be used, the maximum percentage error in computing the final body volume, due to errors in reading pressure, would be reduced. Finally, he noted that a small ratio of chamber to subject volume would effect a smaller error in the final computed volume.

Kohlrausch (7) suggested that the fat and ash content of an animal could be determined from density, provided the amount of protein was known. He constructed an insulated steel chamber (80 x 30 x 25 cm.) of 60 liters capacity with a removable door containing a rubber gasket to make a hermetic seal. The chamber was fitted with valves arranged so that moist air could be introduced into the chamber after it was partially evacuated. Another valve served as a passage for introducing a given quantity of air into the chamber. Pressures greater than atmospheric were used in this procedure to make the density determinations. The compression was accomplished by displacing a volume of air with a known quantity of water, similar to the procedure in the method of Pfleiderer. A water manometer was used for recording pressure changes. With this procedure, Kohlrausch was able to compute the volume of inert objects with great accuracy and precision. He subsequently measured the volumes of four dogs and obtained a range of 1.046 to 1.074 for their computed densities. However, no correlation between density and fat content, as measured by chemical analyses, was reported, but the fat content of these dogs ranged from 6.2 to 12.2% of body weight. Likewise, the precision with which the volume of the dogs was measured was not reported.

In a subsequent experiment, Kohlrausch (8) took one dog, not sacrificed in the previous experiment, and subjected it to several months of heavy work on a treadmill and again determined its density and active muscle mass (from basal metabolic rate). Its density increased from 1.054 to 1.074. The active muscle mass increased from 1676 to 1750 grams, and it was estimated that fat content decreased from 1217 to 609 grams. The body weight of the dog also decreased from 10,805 to 9060 grams.

Bohnenkamp and Schmäh (9) measured the body volume of humans by a procedure essentially the same as those described above. Instead of compressing the gas inside the chamber with air, they injected a known quantity of oxygen. Their theory was based on the fact that the oxygen would distribute itself equally throughout the respiratory passages, which are not part of the solid body mass. No mention was made, however, of the extent of pressure changes caused by the consumption of the injected oxygen. Corrections for temperature changes were made in computing body volume, but vapor pressure corrections were eliminated as saturated conditions were maintained inside the chamber. The results reported were average density values. For males the average was 1.095, and for females 1.07, with extreme single values ranging from 0.98 to 1.13.

Noyons and Jongbloed (10) criticized the method of Bohnenkamp as being very difficult to use routinely, even though its principle of operation was satisfactory. They stated that the method required an accurate knowledge of temperature, relative humidity, and the degree of gasous exchange due to respiration. Furthermore, the operation required the assistance of several people, and the calculation of density from the experimental data was quite tedious. Consequently, these investigators devised a method that theoretically would allow the determination

of density as a function of weight and pressure only. The procedure consisted of weighing the subject very accurately in an atmosphere of two different pressures, and then the difference in weight, after correcting for losses due to insensible perspiration, gave an indication of body volume and density.

In a subsequent investigation, Jongbloed and Noyons (11) measured the body volume of humans with the apparatus described above. The results showed a mean density of 1.080 ± 0.007 for 20 determinations made within several weeks on the same person. They noted also that pressures greater than atmospheric were more comfortable to the subjects than pressures less than atmospheric.

In all of the above mentioned procedures, the greatest difficulties in measuring volume seem to be due to gradual changes in temperature, relative humidity, and composition of respiratory gases. In view of this, Wedgewood and Newman (12) proposed the use of imposing a sine wave of changing volume on these variables. They also indicated that the procedure would be easy to execute. Unfortunately, no details of their apparatus are available, and apparently they have temporarily abandoned their project.

Liuzzo et al. (13) constructed an apparatus that was used to measure body volume of guinea pigs. It consisted of two desiccator jars, each of 2600 ml. capacity, that could be interconnected or separately connected to the atmosphere with a valve. Each jar contained a thermistor for recording temperature, and some suitable arrangement for maintaining the air inside each chamber in a saturated condition. One jar, which was used as the standard, was connected to a vacuum pump with a suitable

valve arrangement so that it could be partially evacuated. A U-tube mercury manometer was used to record pressure. Pressures less than atmospheric were used. Instead of compressing the air inside the subject chamber, it was decompressed by a known amount, the degree of which was determined by the value of the initial vacuum in the standard chamber. The equation used to compute the volume of a subject (V_o) is given below. This equation includes a factor which compensates for temperature changes in the standard chamber, but no such correction factor for the subject chamber. It does not account for changes in vapor pressure, but this effect was minimized by maintaining saturated conditions in each chamber.

$$V_o = V_2 - \frac{P_1 - P_2}{P_2} V_1 \frac{273}{273 + \Delta T} \quad (2)$$

P_1 = initial pressure of standard chamber
P_2 = pressure of system with jars interconnected
V_1 = volume of standard chamber
V_2 = volume of subject chamber
ΔT = temperature change in standard chamber

With this procedure, Liuzzo *et al.* attempted to establish a relationship between body density and composition, so that it could be used to predict the total fat content of live guinea pigs. Two experiments were conducted; in the first, density was correlated with total carcass fat, water, protein, and ash with values of -0.70, 0.67, 0.68, and 0.56, respectively. In the second experiment, the correlation coefficients were slightly higher, being -0.82, 0.81, 0.72, and 0.72, respectively. These higher values were partially a result of using a greater absolute pressure in the procedure for determining volume. They stated that this method was much more rapid to execute than those reported by previous investigators. He also stated that the contents of the elimentary tract did not significantly alter the relationship between body density and composition.

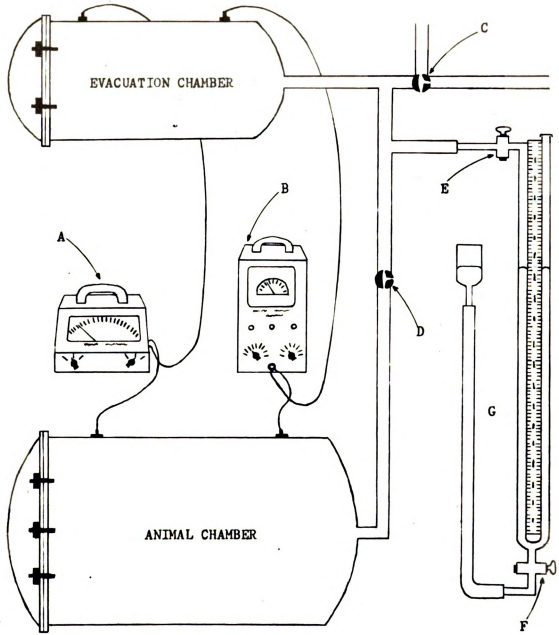
In a previous experiment, Gnaedinger (14) determined the density of 26 male humans by air displacement and compared the values with underwater weighing. A positive relationship ($r = 0.361$) existed between the values obtained by the two methods, but a comparison to composition was not possible, since neither method had been validated by direct comparison studies. The apparatus (Figure 1) and procedure were essentially the same as that used by Liuzzo, with a few modifications. The subject chamber was of 460 liters capacity and the standard chamber was 180 liters. Pressures less than atmospheric were used to measure volume. Also, a different equation for computing body volume from the experimental data was used and is given below. This equation accounts for changes in

$$V_o = V_2 - V_1 \frac{\frac{P'_s - VP}{T'_s} - \frac{P^\circ_s - VP}{T^\circ_s}}{\frac{BP - VP}{T^\circ_a} - \frac{P'_L - VP}{T'_a}} \qquad (3)$$

V_o = volume of subject
V_1 = volume of standard chamber
V_2 = volume of subject chamber
P'_s, T'_s = pressure and temperature of standard chamber after interconnection of the two chambers
P°_s, T°_s = pressure and temperature of standard chamber before interconnection or at initial vacuum
(P'_a, T'_a) = pressure and temperature of subject chamber after interconnection of the two chambers
BP, T°_a = pressure and temperature of subject chamber before interconnection or at barometric pressure
VP = vapor pressure of water at the respective temperature and pressure

relative humidity and temperature in both chambers. However, in this study, vapor pressure corrections were not made in the standard chamber, since all the air before entering this chamber, was dried to a constant level.

The individuals used in this study ranged in condition from obese to very thin, and the values obtained for density were definitely related



A- HYGROMETER
B- THERMISTOR
C&D- 3-WAY VALVES
E&F- GLASS STOPCOCKS
G- U TUBE MERCURY MANOMETER AND RESERVOIR

Figure I. Diagrammatic drawing of the apparatus designed to measure body volume by air displacement.

to their condition. The values for density of this group ranged from 1.045 to 1.167. The greatest difficulty of this procedure was the inability to obtain precise measurements of volume from day to day. Corrections for relative humidity resulted in more precision, but the sensitivity of the electric hygrometer was a limiting factor in obtaining accurate values for relative humidity. Another factor influencing overall accuracy was the uncertainty of getting a representative temperature reading of the air inside each chamber, since the apparatus was located in a place where the ambient temperature was considerably different from body temperature.

Density Determination by Helium Dilution

Since many difficulties are inherent in the procedure for determining body density by air displacement, it was only natural that some other procedure be tried. Consequently, the helium dilution technique was developed. This technique can be considered as a modified air displacement method. The principle involves mixing a fixed, known quantity of helium with an unknown volume of air, and a subsequent determination of the resultant concentration of helium in the air. Thus, when part of the air in a chamber of known size, is displaced by a solid object, the helium concentration of the remaining air will increase in proportion to the volume of air displaced. The increase in helium concentration is then used as the basis for calculating body volume.

Walser and Stein (15) were apparently the first to employ this principle, and they used it to measure the body volume of 10 cats. They introduced a known quantity of helium, by a vacuum procedure, into a desiccator jar containing a cat. After allowing sufficient time for

the helium to equilibrate with the air inside the chamber and respiratory passages of the animal, a sample was withdrawn and analyzed for helium concentration in a Cambridge Analyzer. This analyzer detected helium by the thermal conductivity principle. The volume of the animal was then computed with equation 4. This equation does not account for changes in

$$\text{volume of animal} = \text{volume of empty chamber} - \left[\frac{\text{volume of gas added}}{\text{final conc. of added gas}}\right] \quad (4)$$

temperature and relative humidity of the air inside the subject chamber, but Walser allowed for thermal equilibrium before the gases were mixed. Helium was used as the added gas, because of its inert nature, its negligible solubility in water and tissue fluids, and also because it has a high coefficient of thermal conductivity.

Perhaps the greatest contribution to the helium dilution technique was made by Siri (16). He constructed an apparatus for measuring the body volume of human beings. The principle was the same as that mentioned above. The greatest improvements in this technique, however, were the method of measuring helium concentration and the computation of body volume. He constructed an electronic circuit, which possessed exceptional current stability, to power the thermal conductivity cell. Consequently, the signal from the cell, resulting from a change in the thermal conductivity of the gas flowing through it, could be read with great accuracy and reliability. This was important since the value of this signal was the parameter that reflected body volume. The equation used to compute volume included factors which compensated for changes in relative humidity and temperature of all the gases involved. Siri also performed a detailed estimation of errors for this procedure. This estimation established the

magnitude of error that could be tolerated in each detail of design in order to measure volume with a standard deviation of ± 0.1 liter.

With this apparatus, Siri was able to measure the volume of inert objects for which the standard deviation from the mean was ± 0.028 liter. The density values that he subsequently determined on a heterogenous group of men and women, ranging in weight from 55 to 97 kg., ranged from 0.990 to 1.076. Siri states that even due to the unassessable errors inherent in measurements of biological subjects, the standard deviation of a single measurement would appear to be no greater than ± 0.21 liter.

Estimation of Total Body Fat Content from Live Body Density

Numerous investigators attempted to predict total fat content of animals as a function of density from an equation that best fits the relationship between these two variables. Morales et al. (17) developed a theoretical equation from experimental data, relating body fat and density of eviscerated guinea pigs (equation 5).

$$\% \text{ fat} = 100 \left(\frac{5.135}{\text{density}} - 4.694\right) \qquad (5)$$

Rathbun and Pace (18) subsequently tested this equation for goodness of fit with experimental data that they obtained on body density and fat content of eviscerated guinea pigs. Their data showed a slightly different relationship (equation 6).

$$\% \text{ fat} = 100 \left(\frac{5.501}{\text{density}} - 5.031\right) \qquad (6)$$

Due to a slight discrepancy between whole body density and eviscerated carcass density, Morales (17) derived a theoretical equation relating fat content of the whole body to its density (equation 7).

$$\% \text{ fat} = 100 \left(\frac{5.362}{\text{density}} - 4.880\right) \qquad (7)$$

Likewise, Pitts (19) derived a slightly different equation from his experimental data on guinea pigs (equation 8).

$$\% \text{ fat} - 100 \left(\frac{4.183}{\text{density}} - 3.790\right) \qquad (8)$$

Rathbun (18) also derived a provisional equation for the conversion of human body density to the corresponding fat percentage (equation 9). The derivation was done by employing the basic equations that Morales used for guinea pigs. The data which served as limits for use in these equations were the values for density of human fat, 0.918 (20) and density of the fat-free human body, 1.10 (21).

$$\% \text{ fat} = 100 \left(\frac{5.548}{\text{density}} - 5.044\right) \qquad (9)$$

Messinger *et al.* (22) subsequently used equation 9 to compute body fat and water of guinea pigs with considerable accuracy.

Kraybill et al. (23) determined the density of eviscerated cattle by water displacement, and from these data and the values for total fat content derived equations for estimating percent fat (equation 10) and percent water (equation 11).

$$\% \text{ fat} = 100 \left(\frac{4.802}{\text{density}} - 4.366\right) \qquad (10)$$

$$\% \text{ water} = 100 \left(3.896 - \frac{3.486}{\text{density}}\right) \qquad (11)$$

The derivation of equation 11 was based on a mean value of 72.6% water in the lean body mass.

Kraybill *et al.* (24) continued their work with swine. They found that a close relationship existed between the fat content of the eviscerated carcass and its density. Likewise, fat content and backfat thickness were closely correlated. Consequently, these investigators established a theoretical equation which could be used to predict fat content of the

whole body from the density of the eviscerated carcass (equation 12).

$$\% \text{ body fat} = 100 \left(\frac{5.405}{\text{density}} - 4.914\right) \quad (12)$$

Likewise, an equation for predicting body water was derived (equation 13).

$$\% \text{ body water} = 100 \left(4.400 - \frac{4.021}{\text{density}}\right) \quad (13)$$

Siri (25) made a study of 100 normal human subjects, ranging in age from 20-80 years, to establish values and natural variations in fat, water, and nonfat solids. Body water was determined by tritium dilution and density by his helium dilution method described above. Body fat was calculated with equation 14, in which the constants depend on the respective densities of water, fat and lean tissue solids. This study showed

$$\text{fat} = 2.66 \times \text{volume} - 0.78 \times \text{water} - 1.9 \times \text{weight} \quad (14)$$

wide deviations in body composition from lean to fat persons and wide variations in groups of subjects with identical densities or body water. Siri states that the empirical formulas now used for fat estimation are fairly correct for limited ranges in body composition, but are of little value for individual subjects when more reliable values are desired.

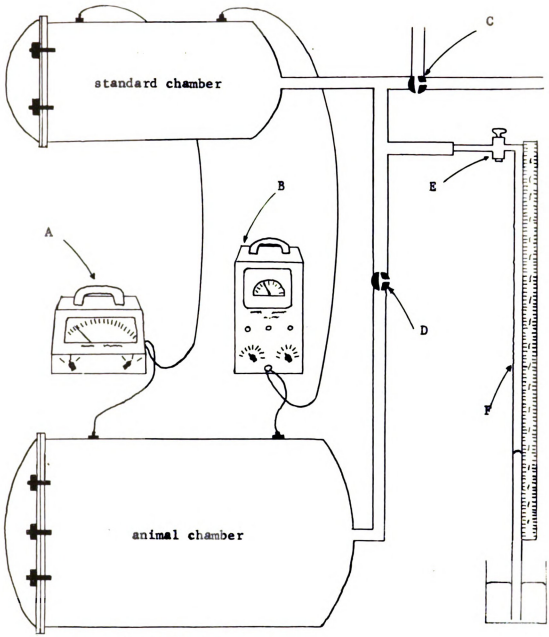
EXPERIMENTAL PROCEDURE

Experimental Animals

Twenty four market weight hogs were obtained from the Michigan State University swine farm and used in this study. They ranged in live weight from 181 to 220 pounds. The group was selected without regard to breed or previous treatment so that various degrees of fatness were represented. All animals were held on the same ration for at least one day in order to standardize the contents of the digestive tract. Twenty four hours before making the volume measurement, all feed was removed, but water was available at all times. The first 9 animals were injected intramuscularly with 3 cc. of the tranquilizer, Sparine, (50 mg. per cc.) about one hour prior to measurement. The purpose of the tranquilizer was to make the animals lie quietly while in the chamber. The treatment did not appear to greatly reduce the animal's restlessness; therefore, it was discontinued.

Determination of Body Density by Air Displacement

APPARATUS: The apparatus used to measure body volume by air displacement is shown schematically in Figure II. The dimensions of the animal chamber were approximately 75 x 125 cm., but the volume was reduced to 460 liters by welding to the sides air tight baffles that spanned the length of the chamber (Figure III). This arrangement reduced the width of the chamber to 41 cm. The standard chamber had a capacity of approximately 180 liters. Each chamber could be sealed hermetically by bolting the door against a flange containing a rubber gasket. The chambers could be interconnected or each could be connected separately to the atmosphere with a 3-way valve (valve D). Each chamber contained: (a) a squirrel



A = hygrometer
B = thermistor
C&D = 3-way valves
E = glass stopcock
F = mercury manometer, cistern type

Figure II. Schematic of apparatus designed to measure body volume by air displacement

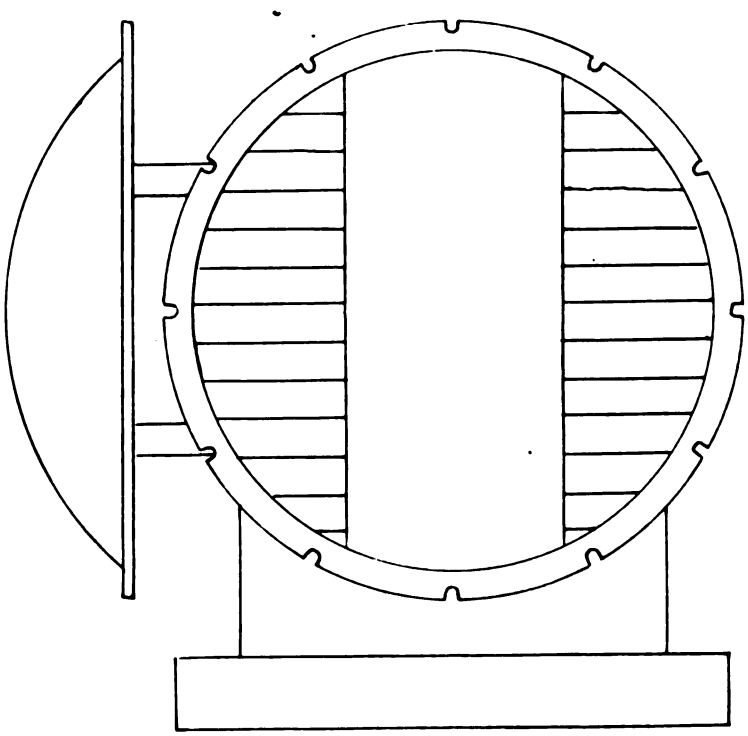


Figure III. End view of open animal chamber showing location of baffles

cage fan (50 cfm.) for rapid circulation of the air, (b) a thermistor for reading temperature, and (c) an electric hygrometer sensing element for reading relative humidity. In the animal chamber, these components were mounted at one end and protected with a metal guard.

The vacuum gauge was a cistern-type, rising-stem manometer. This type was chosen over the U-tube, because the total excursion of the mercury due to a given pressure change was observed along one scale instead of being divided equally on two scales. Also, by having the volume of the cistern relatively large compared to the volume of the stem, a unit change of mercury level in the stem would result in a negligible change of the level in the cistern. Consequently, the maximum percentage error resulting from uncertainties in pressure readings were reduced with this type of gauge. The manometer was mounted permanently on the apparatus and the scale was calibrated to read directly in absolute pressure, using 740 mm. of mercury as barometric pressure.

PROCEDURE: The procedure for measuring body volume was as follows: The animal was placed in the chamber facing the door in order to avoid the direct effects of expired air upon the thermistor and hygrometer sensing elements. The door was then hermetically sealed, but the air inside the chamber was allowed to equilibrate with the atmosphere until the chambers were interconnected. A vacuum was drawn on the standard chamber down to an absolute pressure of about 345 mm. of mercury, after which a short time was allowed for temperature equilibration. The pressure of the standard chamber (P_S°) was then read simultaneously with its temperature (T_S°) by closing stopcock E at the instant that the temperature was read. Closure of this stopcock held the mercury level at the point where the corresponding temperature was read, since there was a

time delay between reading and recording the data. Immediately thereafter, the barometric pressure (BP) and temperature of the animal chamber at barometric pressure (T°_{a}), were recorded concurrently with interconnection of the two chambers (valve D). The ambient barometric pressure was not necessary in this case, and a value of 740 mm. was used in all the calculations. This was compatible with the pressure readings taken from the manometer, since the manometer was calibrated with reference to 740 mm. of mercury to read directly in absolute pressure. After connecting the two chambers, about two minutes were allowed for pressure and temperature to establish a reasonable equilibrium, then the animal chamber was disconnected from the standard chamber and connected again to the atmosphere. At this time, the following manipulations and recordings were made as nearly simultaneously as possible: (a) temperature of animal chamber ($T^{\prime}_{a}$), (b) closure of stopcock E, (c) temperature of standard chamber ($T^{\prime}_{s}$), (d) pressure of animal chamber ($P^{\prime}_{a}$) and standard chamber ($P^{\prime}_{s}$), which in this case are equal. The relative humidity inside the chambers was not recorded, since vapor pressure corrections were not included in the equation for computing volume. It was observed that vapor pressure did not change appreciably during the course of a run. Since the uncertainty in sensing relative humidity was quite large (± 2% of full scale), it was deemed best to delete it from the equation. The volume of the animal (V_o) was computed with equation 15.

$$V_o = V_2 - V_1 \frac{\frac{P^{\prime}_{s}}{T^{\prime}_{s}} - \frac{P^{\circ}_{s}}{T^{\bullet}_{s}}}{\frac{BP}{T^{\circ}_{a}} - \frac{P^{\prime}_{a}}{T^{\prime}_{a}}} \qquad (15)$$

V_1 = volume of standard chamber
V_2 = volume of empty animal chamber

When the factors compensating for vapor pressure changes are included, equation 15 becomes:

$$V_o = V_2 - V_1 \frac{\frac{P_s' - VP}{T_s'} - \frac{P_s^\circ - VP}{T_s^\circ}}{\frac{BP - VP}{T_a^\circ} - \frac{P_a' - VP}{T_a'}} \qquad (16)$$

VP = vapor pressure of water at the corresponding temperature and pressure

In this study, three measurements of body volume were made on each animal according to the above procedure, and the average of the three was taken as apparent volume. Density was then computed with equation 17:

density = weight/volume (17)
weight = live weight of animal immediately before the volume measurement

Preliminary studies on measuring the volume of the empty animal chamber showed quite large variations in the average values obtained from day to day. Thus, each day prior to measuring the animal volume, a volume measurement was made for the empty animal chamber. This served as a correction factor and minimized the day to day variation in measuring volumes.

Determination of Body Density by Helium Dilution

APPARATUS: The apparatus used to measure body volume in this study was modeled after the method developed by Siri (16), for measurement of human body volume. The various individual components were changed when necessary in order to adapt the system to measurement of the body volume of pigs. The chamber used to confine the animals was the same chamber previously described for air displacement and is shown in Figures II and III.

The helium metering system is shown schematically in Figure IV. The helium chamber was a propane gas tank and had a capacity of about 22 liters.

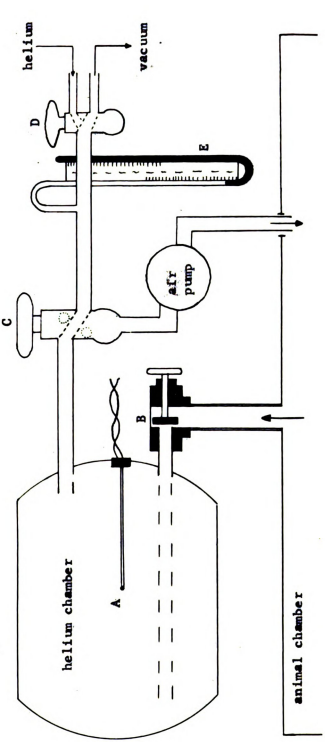


Figure IV. Schematic of helium metering system

Two 1-inch threaded pipes were welded in the chamber and served as gas inlets and outlets. A thermistor was mounted through the chamber opening and positioned in the center. An air tight seal was made around the thermistor wires with Epoxy cement. The helium tank was mounted permanently on the animal chamber with a 1-inch pipe and a Jenkins steam valve. Another arrangement of stopcocks and pipe fittings served to: (a) evacuate the chamber, (b) introduce helium into the evacuated chamber, (c) maintain the helium filled chamber at atmospheric pressure without introducing any air, and (d) inject the helium quantitatively into the animal chamber without altering its pressure. An Eberbach air pump capable of producing 30 psi, or 24 in. of mercury, and of moving 1.5 cubic feet of air per minute was used to inject the helium into the animal chamber. The pump was allowed to circulate the air-helium mixture between the two chambers throughout the duration of the measurement. Equilibrium between the two gases was attained in about 4 minutes. A Cenco Hy-Vac vacuum pump was used to evacuate the helium chamber. The gauge used to record vacuum was a closed-end manometer.

The helium analyzer consisted of a thermal conductivity cell, a power supply, and a potentiometer. All these components are commercially available. The cell (Gow-Mac model 9737, 30-S) contained 8 tungsten, type 9225, resistance filaments mounted in a brass, 2-pass T/C cell. The power supply produced a constant direct current to the cell and was a Gow-Mac model 9999-C-1:1 unit. The potentiometer for recording the signal from the cell was a Sargent model SR recorder, 2.5 mv.

Since the signal from the 8 filament cell exceeded the range of the recorder, an attenuating resistance circuit was wired to series between

the power supply and cell (Figure V). The circuit consisted of two resistance decades wired in series to give a total resistance of 10 ohms in 0.1 ohm steps. This circuit allowed for most of the signal to be attenuated, leaving only the residual signal to be read on the recorder. The attenuation was accomplished without reducing the sensitivity of the instrument or the residual signal. To determine the amount of signal attenuated, the decades were calibrated with reference to the deflection obtained on the recorder for a 0.1 ohm change in resistance. By multiplying the number of ohms required to attenuate the signal by the deflection per ohm, the total signal attenuated was computed in terms of arbitrary units of deflection. The total output signal was the sum of the attenuated signal and the residual. In this study, the sensitivity of the power supply was adjusted so that 0.1 ohm gave a deflection of 65 units on a full scale of 100 units per 2.5 mv.

The thermal conductivity cell was operated at constant temperature in a mineral oil bath (Figure VI) that was maintained at a temperature of 47 ± 0.01°C. This value was chosen, since the regulation was best at this temperature. The oil bath tank was made of plexiglas, with dimensions 9 x 10 x 14 inches, and was insulated with 1 inch Styrofoam. A plexiglas cover served as a support for suspending the cell in the oil. The temperature of the bath was regulated with a thermistor-actuated Sargent Thermonitor. Two heaters were used with this unit, one a knife type heater of 250 watts, and the other a cycling 60 watt light bulb. The stirrer for circulating the oil was mounted firmly on a support that was independent of the oil bath, so that the vibration would not affect the cell. The power supply, thermonitor, and recorder were partially

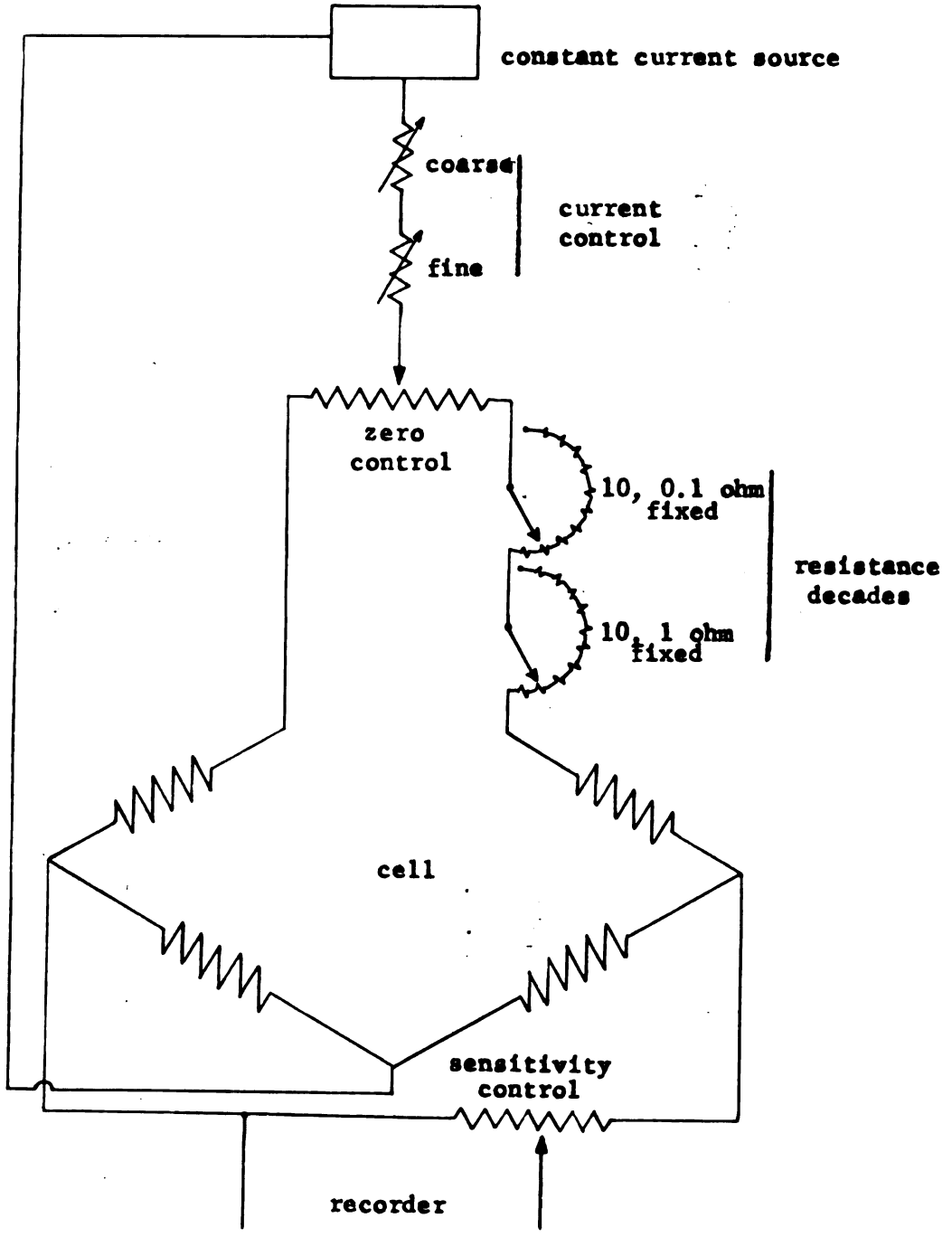
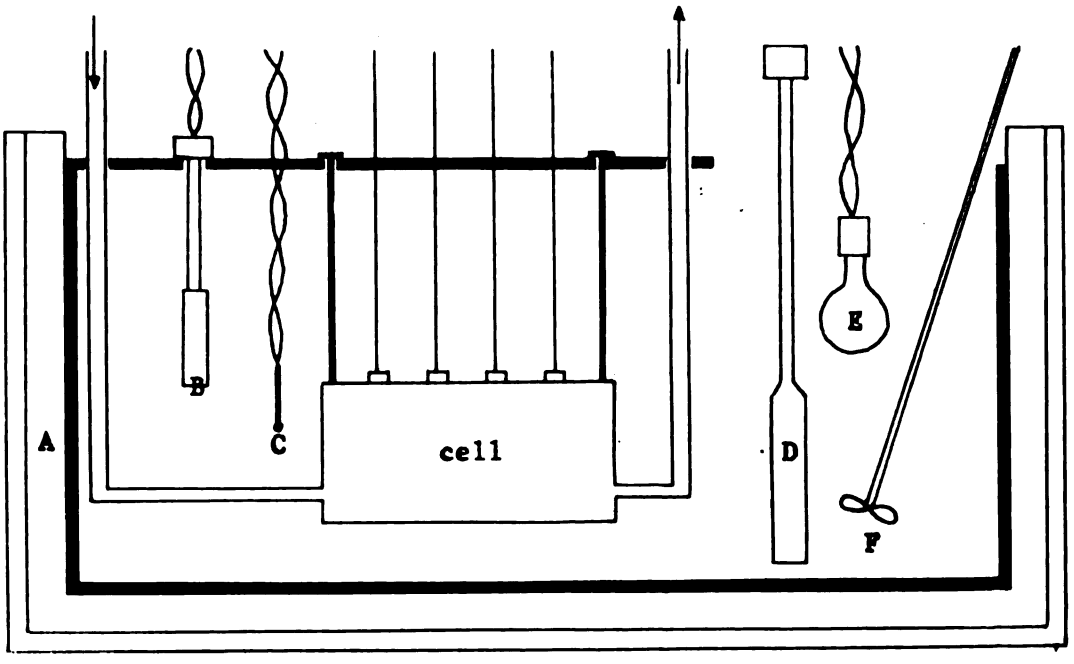


Figure V. Schematic of helium analyzer showing location of resistance decades



A = styrofoam insulation, 1 inch
B = thermistor thermoregulator
C = thermistor
D = heater, 250 watts
E = heater, 60 watt light bulb
F = stirrer

Figure VI. Schematic of oil bath and accessories

enclosed in a plywood cabinet, in which a 40 watt light bulb served as a crude thermoregulator.

The gas sampling system for monitoring the reference and chamber gases through the cell is shown schematically in Figure VII. The water cans (5 gallon metal reagent containers) were interconnected at the bottom, thereby forming a common drainage point. Rubber stoppers and tygon tubing were used to connect the cell to the cans, so that an air tight, closed system was formed. Thus, as the water flowed out at the bottom of the cans, air was drawn through both sides of the cell. Also, since there was no resistance to the flow of gas in the system, the water levels remained equal, thereby assuring an equal flow rate through each side of the cell. The flow rate in this system ranged from about 800 to 400 cc. per minute as the water level in the cans decreased. The reference gas, which was dry air in this case, was brought in from outside the building so that its composition would not change during a run. Calcium chloride was used to dry the reference and the chamber gases before they entered the cell.

PROCEDURE: The procedure for measuring body volume was similar to that used by Siri (16). Before the animal was put into the chamber, adequate preparations were made so that the measurement could be performed without interruption and as rapidly as possible. The helium chamber was evacuated down to an absolute pressure of about 5 mm. of mercury, filled with helium, and again evacuated to a pressure of about 1 mm. This procedure appeared to be adequate to remove all the air from the chamber and to fill it with pure helium. The current to the cell was then adjusted to approximately 110 ma. and the recorder was zeroed with

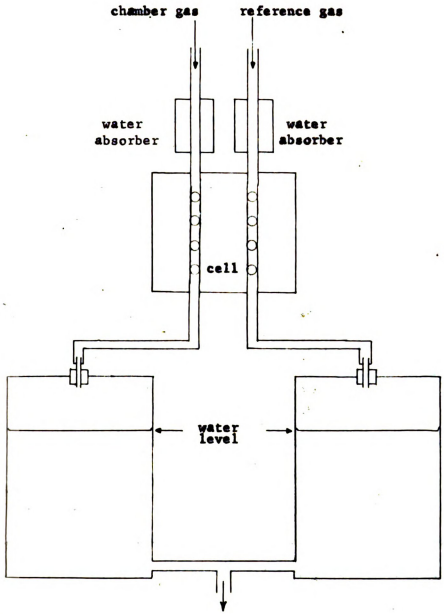


Figure VII. Schematic of gas sampling system

the reference gas flowing through both sides of the cell. The outlet from the air pump (Figure IV) was inserted through a hole in the animal chamber, which was slightly larger than the outside diameter of the pump outlet. This hole served to keep the air of the animal chamber in equilibrium with atmospheric pressure. It also served as an air inlet while the air-helium mixture of the chamber was being monitored through the cell. The animal was then placed in the chamber and the door bolted tight enough to prevent air leakage. Immediately thereafter, one side of the cell was switched from the reference to the chamber gas, and a deflection of the recorder needle was obtained which corresponded to the gasous exchanges due to respiration.

The system was now ready for the helium injection. The necessary recordings and manipulations were made in the following order: (a) temperature of the helium, (b) temperature and relative humidity of the air in the animal chamber, (c) interconnection of the helium and animal chambers with valve B (Figure IV), (d) resistance value of the decade, and (e) temperature of the oil bath. The curve on the recorder was also marked at the exact time when the helium injection was started (manipulation c). As the helium concentration of the gas in the chamber increased, a corresponding positive deflection was obtained on the recorder. However, as the deflection increased beyond the width of the chart, the resistance on the decade was correspondingly increased until the signal was again brought back on the chart. About 4 minutes were required for the helium-air mixture to reach equilibrium throughout the chamber and the animal's respiratory passages. This point was determined simply by observing the shape of the recorded signal, as an inflection point occurred when equilibrium was reached (Figure VIII). The recording was continued

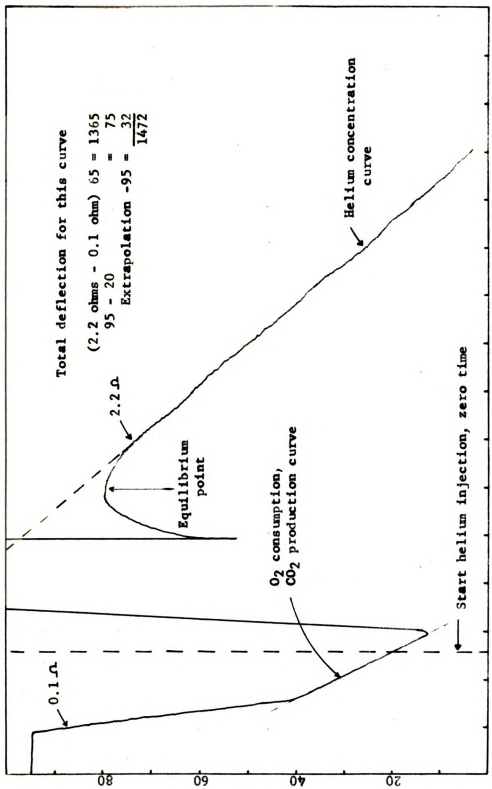


Figure VIII. Schematic drawing of a typical helium concentration curve

for at least 6 minutes beyond the equilibrium point, during which time the signal produced a curve of constant negative slope. The decade resistance was adjusted so that the curve of negative slope extended the full width of the paper. This curve was extrapolated to zero time, or the time of helium injection, at which point the helium concentration in the chamber was theoretically at a maximum. The deflection at this maximum was the value used to compute animal volume and is designated as R_o in equation 18.

The following equation was used to compute body volume:

$$V_o = \frac{V_2R_2(R_o-R_1) - V_1R_1(R_o-R_2) + v(S_o-S_1)(R_2-R_1) - v\,(S_2-S_1)(R_o-R_1)}{R_o(R_2-R_1)} \quad (18)$$

V_o = volume of animal
V_1 = volume of reference 1 = 83.16 liters
V_2 = volume of reference 2 = 103.56 liters
v = volume of helium chamber = 22.075 liters
R_o = observed deflection at zero time with animal in the chamber
R_1 = computed deflection at conditions of R_o and with reference to V_1
R_2 = computed deflection at conditions of R_o and with reference to V_2
$S_o = R_o/\gamma$
$S_1 = R_1/\gamma$
$S_2 = R_2/\gamma$

The use of this equation required calibration of the apparatus between two references of known volume. The volumes used are indicated above. This range was sufficient to bracket the range of volumes of the animals used in this study. A number of runs were made on each reference according to the above procedure and a plot of deflection versus helium concentration was made (Figure IX). Deflection values were obtained by extrapolating the dilution curve of the recorded signal to zero time as previously described. Helium concentration was computed with equation 19.

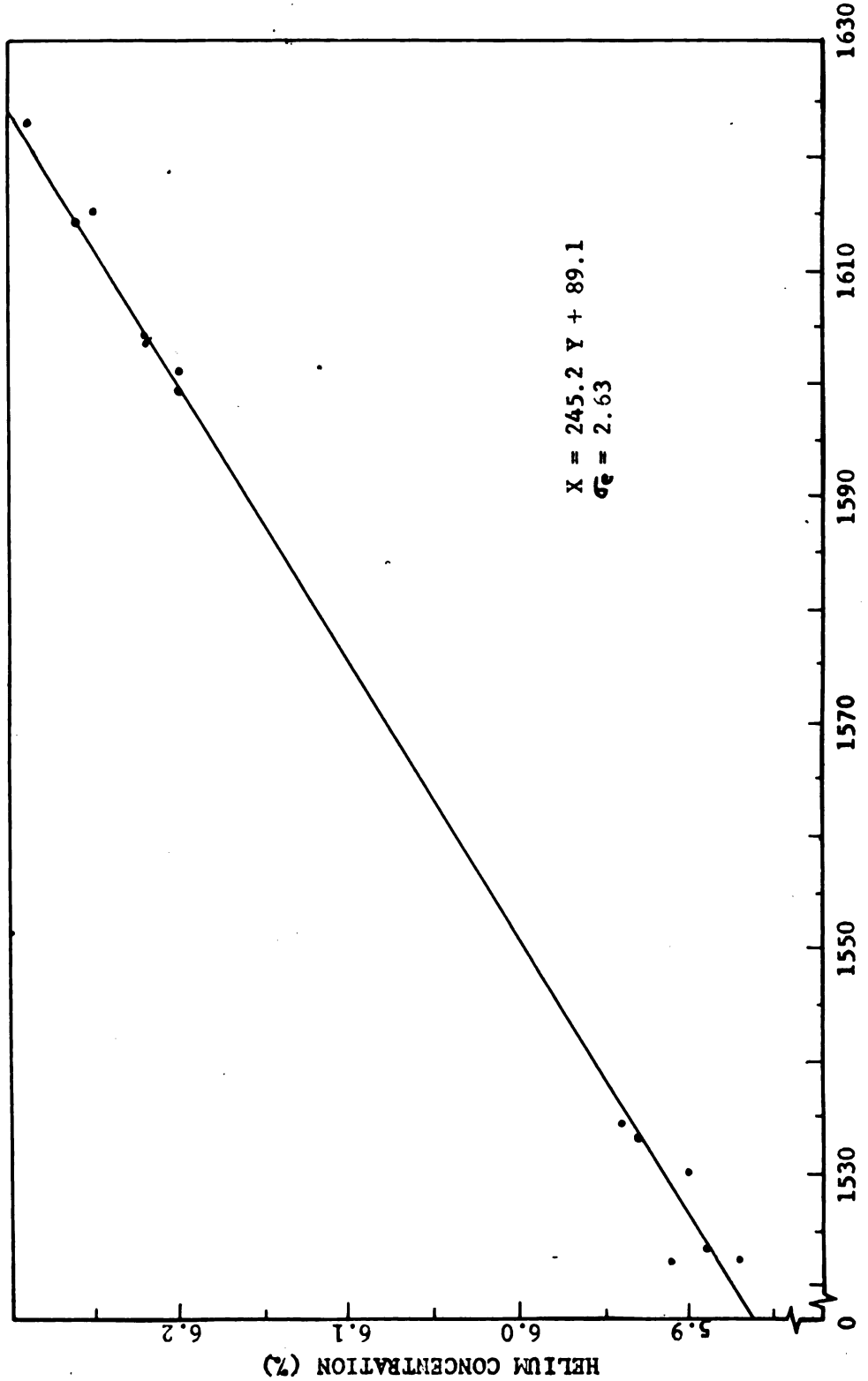


Figure IX. Graph of deflection values versus helium concentration at both reference volumes

$$c = \frac{v}{(V_c - V_i)\,\gamma + v} \qquad (19)$$

v = volume of helium chamber
V_c = volume of empty animal chamber
V_i = volume of reference being used

$$\gamma = \frac{T_h}{T_c}\,\frac{(P - p)}{(P)} \qquad (20)$$

T_h = temperature of helium at time of mixing
T_c = temperature of animal chamber at time of mixing
P = barometric pressure or 740 mm.
p = vapor pressure of water at T_c and P

The plot of deflection versus concentration was assumed to be linear over the range of the reference volumes. Thus, a linear equation expressing this relationship between these two variables was computed (equation 21). From equations 19, 20, and 21, the values for R_1, R_2, S_o, S_1, S_2, and γ were computed for use in equation 18.

$$R_i = 245.2\ c_i + 89.1 \qquad (21)$$

Sampling and Analysis of Carcass

The experimental animals were weighed, immediately put in the chamber, and measured for body volume. Helium dilution was run first followed by air displacement, without removal of the animals from the chamber. About 30 minutes were required to complete both measurements. The animals were killed by bleeding within one hour after completing the measurements.

The amount of blood was computed from the difference in weights taken before and after bleeding and a sample of blood was collected for chemical analysis. The carcass was then dressed according to conventional procedures. The scurf, hair, and toenails were collected quantitatively. The composite was air dried, ground twice in a meat grinder and sampled for chemical analysis. The values for the composition of hair reported herein, were obtained from a composite sample of the hair of six animals.

These hair samples were randomly selected, ground together, and analyzed as one sample. The head was removed, leaving the jowls on the carcass, and sealed in a plastic bag. The carcass was eviscerated over a container which served to catch any body fluids and blood clots that remained in the body cavities. The carcass was then split and chilled for 24 hours prior to being frozen at -20°F. Length and backfat thickness (1st rib, last rib, last lumbar vertebra) measurements were taken on the chilled carcass.

The viscera was divided into 3 parts in order to determine the contribution of each to the intact animal. The lungs, trachea, esophagus, heart, liver, spleen, and kidneys were removed and sealed together in a plastic bag. The intestines and stomach were emptied and along with the caul fat composed the second part. The third part included the intestinal contents, blood clots, and any remaining body fluids. All parts were weighed and then frozen at -20°F. Thus, each animal was dissected into 7 separate components for chemical analysis. This method of dissection yielded no less than 99% recovery of the weight of the live animal.

To get a homogenous sample of the frozen components for chemical analysis, the following procedure was used: Each component was cut into strips about 1/8 in. in thickness and up to 3 in. in width with an electric meat saw. The frozen strips were then ground 6 times, after which a sample weighing approximately 70 gms. was taken for analysis. Five plates, ranging in size from 1/2 in. to 1/8 in. were used. The sample was ground twice through the 1/8 in. plate. A 1.5 HP, Enterprise, model 2632 electric meat grinder was used. With this procedure, the bones in the carcass and head were sufficiently macerated and mixed with the meat to yield a homogenous sample. The teeth and some small pieces of bone

caused a little difficulty, since some of the fragments were still too large to go through the 1/8 in. plate. Also, the teeth dulled the saw blade very quickly.

After grinding, the samples were stored at -20°F until analyzed. Each sample was analyzed for moisture, ether extract, protein, and ash. The amount of moisture was determined according to the procedure of Benne et al. (26) with two exceptions. The disposable aluminum foil dishes used in this study were approximately 15 mm. deep and did not have lids. Also, all samples were dried for 24 hours at a temperature of 100 to 105°C.

The amount of ether extract was determined on the dried samples left from the water determination. The samples were extracted with the Goldfisch Extractor, which was described by Hall (27). The dried samples were enveloped with the aluminum dishes in a cylindrical manner, leaving both ends open so that the extractant would thoroughly penetrate the samples. The dish and contents were then inserted into the extraction thimble. The samples were extracted with anhydrous diethyl ether for 4 hours. The ether was distilled into a collecting vessel and subsequently re-utilized. The tared beakers were then removed from the extractor, dried in an oven at 100-105°C for about one hour, cooled to room temperature in a desiccator, and reweighed. The amount of ether extract was determined from the weight of the residue collected in the beaker after extraction.

The determination of protein was performed according to the Kjeldahl procedure as outlined by Benne et al. (26).

Ash content was determined on samples weighing approximately 5 gms. The empty crucibles (Coors, #3, porcelain) were heated for 10 minutes at

525°C, cooled to room temperature in a desiccator, and tared. The samples were weighed into the crucibles and dried in a hot air oven for at least 12 hours. The dried samples were then ashed at 525°C for 24 hours. The crucibles and residue were removed from the furnace, cooled to room temperature in a desiccator, and reweighed to obtain the amount of ash.

RESULTS AND DISCUSSION

Relationships between Various Density Values

The results of the density determinations are summarized in Appendix Table 1. The values for air displacement ranged from 0.975 to 1.222 with a mean value of 1.075. The range for helium dilution was slightly lower with values of 0.940 to 1.114 and a mean value of 1.017. The values for helium dilution for the first 10 animals were omitted, since the technique of measurement was not valid on these animals.

Theoretical density values were computed with the following equation of Kraybill et al. (23):

$$G = \frac{M}{\frac{F}{D_f} + \frac{M-F}{D_l}} \qquad (22)$$

G = whole body density
M = weight of whole body
F = weight of body fat
D_f = density of pork fat = 0.914 (20)
D_l = density of lean body mass = 1.1 (21)

These values were computed in order to compare them with the densities obtained by helium dilution and air displacement. The values can be assumed to be reasonably correct, since they were determined directly from chemical analysis data. The values ranged from 1.015 to 1.042 with a mean of 1.0312.

The correlation coefficients between the 3 sets of density values are given in Table I. The air displacement densities were correlated inversely and nonsignificantly with both the helium dilution and the theoretical densities. The helium dilution densities were correlated directly but non-significantly with the theoretical values. Thus, the correlation coefficients indicated that the helium dilution densities were

Table I. Summary of correlation coefficients

Variable	Density		
	Air displacement	Helium dilution	Theoretical
Air displacement density	------	-0.126	-0.021
Helium dilution density	------	------	0.134
% carcass moisture	-0.056	0.239	0.918**
% carcass protein	-0.113	0.209	0.825**
% carcass ether extract	0.001	-0.176	-0.931**
% carcass ash	-0.362*	-0.145	0.417*
% ether extract of whole body	-0.008	-0.216	-0.944**
% ether extract of empty body	-0.016	-0.200	-0.935**
Backfat thickness	0.326	0.082	-0.546**

% ether extract: empty body vs carcass	0.991**
% ether extract of carcass vs backfat thickness	0.690**
% ether extract of empty body vs backfat thickness	0.667**
% moisture of empty body vs % ether extract of body(empty)	-0.974**
% moisture of whole body vs % ether extract of whole body	-0.976**
% moisture of whole body vs % ether extract of empty body	-0.971**
% moisture of ether extract-free, empty body vs % ether extract of empty body	-0.579**
% protein: ether extract-free, empty body vs ether extract-free, carcass	0.862**
% moisture: ether extract-free, empty body vs ether extract-free, carcass	0.864**
% ash: ether extract-free, empty body vs ether extract-free, carcass	0.867**
% carcass protein vs backfat thickness	-0.599**
% carcass protein vs length	0.180
% carcass ether extract vs length	0.245

** Significance at the 1% level
* Significance at the 5% level

somewhat more predictive of body composition than the air displacement densities. Table I also includes correlation coefficients for carcass and body composition with the density values obtained by the various methods. The correlation for the densities determined by air displacement with both % carcass protein and % carcass water should theoretically show a positive instead of a negative relationship. Likewise, the values for % ether extract in the carcass and backfat thickness should be inversely related to density, but were both positive. The values under helium dilution are higher than those under air displacement, but all are statistically non-significant. The correlation coefficients discussed above indicated that the helium dilution technique of measuring volume was slightly superior to the air displacement method.

Errors in Measuring Density By Air Displacement

As was previously mentioned in the procedure, the greatest difficulty encountered with the air displacement method was its lack of precision in measuring volumes from day to day. In an attempt to correct for this variation, the volume of the empty animal chamber (an average of 3 determinations) was made each day, prior to measuring the volume of the experimental animals. These data were analyzed statistically in order to ascertain the magnitude of the variation. The values obtained for the volume of the empty chamber ranged from 454.71 to 470.83 liters, with a mean of 464.61 and standard deviation of ± 4.7 liters. An analysis of variance of the data is given below. The analysis showed that there was a significant difference between the means obtained from day to day. There was also a significant difference between the 3 samples that composed each mean.

Table II. Analysis of variance of values obtained for the volume of the empty animal chamber

Source of variation	Degrees of freedom	Mean square	F ratio
Total	38	-----	---
Between means	12	66.42	110.7**
Within means	2	3.57	5.95**
Error	24	0.60	---

An estimation of errors was performed on equation (16) in order to ascertain the source of the variation that consistently occurred in computing volumes. For this estimation, the following limits were established: (1) the maximum error in reading pressure was ± 0.1 mm. on each limb of a U-tube mercury manometer, (2) the maximum error in reading temperature was ± 0.1°C, (3) the maximum error in reading relative humidity was 1% (the accuracy of the electric hygrometer was ± 2% of full scale), (4) the air in the standard chamber was kept dry so that relative humidity corrections were not required in this chamber. Under these conditions, the maximum percentage error in computing a gas volume of 445.43 liters was 2.54%. A maximum percentage error was also computed using equation 15 in order to ascertain the effect of relative humidity on the total error. The limits on this equation were the same as above, with the exclusion of the relative humidity corrections. The maximum error was reduced to 0.79%. Thus, it appeared that relative humidity was a potential source of large error.

In this study, a cistern-type manometer instead of a U-tube was used to read pressure. An estimation of errors was computed with this

type of manometer using equation 15 in order to see its effect on the total error. The value thus obtained for the maximum percentage error was 0.72%. This was a slight reduction over using the U-tube, primarily because readings are taken from only one limb with a cistern-type manometer.

The above estimation assumes that all the errors are additive, but this does not usually happen in actual practice. However, other sources of error which are inherent in measuring live animals are likely to occur and contribute even more to the overall error. For instance, the magnitude of the error resulting from a non-representative temperature reading in the chambers was difficult to ascertain. Since the temperature of each chamber was recorded with a single thermistor, it seems likely that errors as great as $\pm$ 0.5°C were possible. Furthermore, uncertainties in temperature readings undoubtedly increased as the ratio of body temperature to room temperature increased.

The estimation showed that uncertainties in reading relative humidity contributed greatly to the overall error. Furthermore, the accuracy in reading this variable was limited to the accuracy of the electric hygrometer. In view of this, it would appear desirable to delete vapor pressure corrections from the equation used to compute volume. This could be done provided the relative humidity of the air in the chambers was maintained at a constant level of saturation, at least during the duration of a run. However, the assumption of a constant level of saturation may not be valid, since relative humidity is quite sensitive to temperature changes. Also, vapor pressure is affected slightly by barometric pressure according to the Carrier equation, (equation 23).

$$P_H = P_{wb} - \frac{(p - P_{wb})(t_{db} - t_{wb})}{2830 - 1.44\ t_{wb}} \qquad (23)$$

t_{db}, t_{wb} = temperature of dry bulb and wet bulb, respectively
P_H = partial pressure of water vapor
P_{wb} = saturation pressure of water vapor at t_{wb}
p = barometric pressure

Since pressure and temperature changes occurred in both chambers, it appeared likely that the assumption of a constant level of saturation introduced a considerable error in computing volumes.

Errors in Measuring Density by Helium Dilution

A detailed estimation of errors involved in the instrumental design of the helium dilution method was given by Siri (16). He defined the limits in which each variable must be controlled in order to measure volume within a standard deviation of ± 0.1 liter. With the apparatus used in the current study, the volume of an inert object was determined with a mean deviation of 0.81 liter for 8 determinations. Most of this variation appeared to be a function of current adjustment. The power supply was highly stable at any particular current setting. However, the precision with which current could be adjusted from day to day appeared to be the major cause of deviation. The degree of precision was in turn limited by the accuracy with which current could be set on the milliammeter. The meter on the power supply could not be adjusted more accurately than ± 0.1 ma. Ideally, current adjustment should be made with a precision of at least ± 0.01 ma. Thus, the greatest source of error in measuring the volume of inert objects appeared to be adjustment of the current.

The equations and method for computing volume by helium dilution assume that all variables remain constant or that they change at a constant rate throughout the duration of a run. However, the variables did

not change at a constant rate, since the animals displayed various degrees of activity while in the chamber. The effect of these variables on the concentration of helium passing through the cell can be seen by inspection of equations 19 and 20. As the relative humidity of the air in the chamber increased, γ decreased; thus concentration increased. Likewise, as the temperature of the animal chamber increased, so did the concentration of helium. Thus, the effect of temperature and humidity on helium concentration was additive. It is conceivable that these variables may have changed at a more rapid rate immediately after putting the animal in the chamber than at the end of the run. Consequently, the slope of the helium concentration curve would be different at the beginning of a run than at the end. Any change in the slope of this curve introduced uncertainties into its accurate extrapolation to zero time (Figure VIII).

The magnitude of the errors caused by changes in temperature and relative humidity can be approximated by inspection of Figure IX. The points at the bottom of the graph were obtained on measurements of reference 1. Likewise, the points at the top were obtained on measurements of reference 2. The dispersion of these points was due to changes in temperature and relative humidity of the air in the animal chamber. The temperature of the helium at the time of injection also affected the final concentration of helium in the animal chamber. However, subsequent changes in the temperature of the helium chamber had no appreciable effect on the final concentration.

In order to remove the effects of changes in temperature and relative humidity, they will necessarily have to be maintained constant or controlled to change at a constant rate throughout the duration of a

measurement. The effect of relative humidity could be minimized by maintaining the air of the animal chamber in a saturated condition. Saturation of the animal chamber can be accomplished most conveniently by wetting the skin of the animal with water prior to putting it in the chamber. Temperature changes are more difficult to control. The thermal expansion of the air-helium mixture in the chamber is a probable source of error. If expansion of the gas mixture exceeded the rate at which it was being minitored through the cell, some of the helium would be forced out of the chamber. For instance, a temperature increase of 0.5°C per minute would expand the gas at a rate of about 1 liter per minute, yet the flow rate of the gas sampling system did not exceed 500 ml. per minute. In this study, the temperature of the chamber was considerably lower than the body temperature of the animal. Temperature differences up to 10°C were commonly observed. Thus, it appeared likely that the thermal expansion of the air-helium mixture was a possible source of error. The thermal expansion of the mixture could be somewhat minimized by maintaining the temperature of the animal chamber somewhere near body temperature.

The greatest source of error in measuring body volume appeared to be due to the activity of the animals inside the chamber. Most of the animals became excited when enclosed in the chamber. Some fought continuously and to the point of exhaustion in an attempt to escape from the chamber. Others were less excited and fought only intermittently. Thus, the degree of excitement affected the rate of respiration and consequently the rate of heat and moisture accumulation in the chamber. These changes in temperature and humidity were reflected in the slope of the helium concentration curve. The gaseous exchange due to respiration was important, since the cell was responsive to all the gases that passed through

it. The accumulation of carbon dioxide and depletion of oxygen effected a change in thermal conductivity in a direction opposite to that of helium. Thus, this effect was superimposed on the helium concentration curve. The method of correcting for the gaseous exchanges consisted of extrapolating the helium curve to zero time (time of known respiratory gas composition). The accuracy of this correction in turn depended upon a straight line for the slope of the curve that represented the changes in these gases (Figure VIII). Since the activity of the animals was not constant during a run, the slope of the curve was affected in proportion to the degree of activity. Consequently, the slope was not constant and an accurate extrapolation to zero time was virtually impossible. An attempt was made to minimize the accumulation of carbon dioxide in the chamber by absorbing it with Ascarite. A tray of absorbent was placed inside the chamber so that it would absorb the carbon dioxide as the air was circulated around it. This procedure resulted in greater variation in the slope of the curve than when no absorbent was used. This appeared to be due to the degree of activity of the animal. When the animal was restless, its carbon dioxide production apparently exceeded the rate at which it was absorbed by the Ascarite. The opposite appeared to occur when the animal lay quiet.

The carbon dioxide content of the air in the chamber affected the helium concentration in the same manner as did water vapor. Both gases served as diluents for the helium. Thus, if either or both gases are removed from the air-helium mixture, the resultant helium concentration passing through the thermal conductivity cell will be affected proportionally. An appropriate correction can be made for the quantitative

removal of water vapor from a knowledge of relative humidity (equation 20). However, the equation contains no factor to compensate for the removal of carbon dioxide. Consequently, the absorption of carbon dioxide was not valid, since the quantity removed could not be ascertained. A carbon dioxide absorbent was used in the procedure for determining the volume of the first 10 animals in this study. Thus, their values for density were omitted, since the results were not valid.

Another possible source of error was the loss of helium from the chamber due to the rapid respiration of an excited animal. It was observed that some gas (air-helium mixture) was forced out of the chamber with each expiration of the animal. An equal amount of gas (air only) was in turn drawn into the chamber with each inspiration. Thus, the helium concentration of the chamber was being constantly reduced. A correction for this loss can again be effectively performed by extrapolation of helium concentration curve. However, an error would result if the loss of helium did not occur at a constant rate. Any variation in the rate of dilution would cause the slope of the helium curve to change and an accurate extrapolation would be impossible.

Results indicated that the activity of the animals must necessarily be controlled before accurate results can be expected. It is recommended that volume measurements be attempted on anesthesized animals. This would tend to prevent radical changes of the variables resulting from changes in the respiration rate of excited animals. It is also recommended that the animal be moistened with water in order to maintain saturated conditions of the air in the chamber. Also, the temperature of the chamber should be maintained close to body temperature in order to minimize the errors due to the thermal expansion of the air-helium mixture.

Body Composition Relationships

The moisture content of the dressed carcasses ranged from 38.31 to 49.50% with a mean of 45.81%. The moisture content of the empty bodies (the entire live animal minus the contents of the G.I. tract) ranged from 41.73 to 52.54% with a mean of 48.49% (Appendix Table 12). Mitchell and Hamilton (28), working with pigs, reported mean values of 41.41 and 47.92% for the moisture content of the dressed carcasses and empty bodies, respectively. Their data were obtained from animals representing the chuffy, intermediate, and rangy types and were slaughtered at 175 and 225 lbs.

The ether extract content of the dressed carcasses ranged from 31.89 to 46.84% with a mean of 37.45%. The ether extract content of the empty bodies ranged from 27.97 to 41.50% with a mean of 33.50% (Appendix Table 12). Mitchell and Hamilton (28) reported mean values of 43.13 and 37.07% for the fat content of the dressed carcasses and empty bodies, respectively. Thus, the pigs used in their study contained about 5% more fat in the dressed carcasses and about 3.5% more fat in the empty bodies.

The protein content of the dressed carcasses ranged from 11.90 to 14.32% with a mean of 13.19%. The protein content of the empty bodies ranged from 12.54 to 14.77% with a mean of 13.78% (Appendix Table 12). Mitchell and Hamilton (28) reported mean values of 12.14 and 12.04% for the protein content of the dressed carcasses and empty bodies, respectively. Thus, the pigs used in the current investigation had about 1% more protein in the carcasses and about 1.7% more protein in the empty bodies than those used by Mitchell and Hamilton.

The ash content of the dressed carcasses ranged from 1.99 to 3.18% with a mean of 2.75%. The ash content of the empty bodies ranged from

2.20 to 3.15% with a mean of 2.74% (Appendix Table 12). Mitchell and Hamilton's data (28) showed mean values of 2.76 and 2.42% for the ash content of the dressed carcasses and the empty bodies, respectively. The composition of Mitchell and Hamilton's group of animals was slightly different from the group used in this study, with the exception of ash content. Some of the differences in composition of the carcasses may have been due to the fact that the head was apparently included in their carcass analysis. Also, their group of animals was fatter than the group used in this study.

The average weight of the air dried hair (including scurf and toenails) was 1.1 lbs. for the group of animals used in this study (Appendix Table 2). This value was slightly higher than the 0.7 lb. obtained for these components reported by Mitchell and Hamilton (28) on pigs weighing 225 lbs. These authors obtained values of 6.81, 2.49, 87.0, and 5.64% for the moisture, fat, protein, and ash content, respectively, of the air dried hair. The values obtained in this study were 8.25, 1.91, 89.0, and 1.31% for moisture, ether extract, protein, and ash, respectively (Appendix Tables 3 through 6). Thus, the moisture content of the hair was about 1.5% lower in Mitchell and Hamilton's group of animals. This difference may have been due to the degree of air drying of the material. The values for fat and protein agreed favorably between the two groups of animals. The ash content of the hair was about 4% lower for the animals used in the current study.

The composition of blood for the group of animals used in this study was 79.75, 0.1, 18.95, and 1.22% for moisture, ether extract, protein, and ash, respectively, (Appendix Tables 3 through 6). Mitchell and Hamilton (28) reported values of 80.20, 0.04, 18.6, and 1.22% for moisture,

ether extract, protein, and ash, respectively. Thus, the composition of blood for the two groups of animals agreed favorably.

A summary of the means and standard errors for the contribution of each component to the whole animal (Appendix Tables 7 through 10) are shown in Table III. The values indicate the maximum percentage errors resulting from the exclusion of any one component or any combination of components from the analysis of the total animal. The choice of either excluding or including the analysis of any component will depend upon the degree of accuracy desired in the total analysis. However, the use of average values would reduce the maximum errors shown in Table III, without having to completely analyze the various minor components. This would be desirable from a practical standpoint, since only the weights of the components would need to be recorded.

Table III. Contribution of each component to the whole animal as percentages of total moisture, ether extract, protein, and ash.

	Moisture		Ether extract		Protein		Ash	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Carcass	74.08	1.80	89.79	1.44	76.13	1.30	79.11	3.53
Intestines*	5.99	0.68	5.07	0.94	3.95	0.41	1.63	0.31
Viscera**	5.87	0.40	0.95	0.18	4.55	0.25	1.68	0.18
G.I. contents	2.82	0.68	0.19	0.08	0.95	0.29	1.34	0.35
Head tongue	5.38	0.54	3.86	0.78	5.59	0.47	14.39	3.49
Blood	6.13	0.89	0.01	.005	5.19	0.87	1.68	0.33
Hair***	0.09	0.02	0.03	.007	3.63	0.55	0.27	0.06

* Includes the intestines, stomach, and caul fat.
** Includes the liver, lungs, heart, kidneys, spleen, esophagus, and trachea.
***Includes scurf and toenails.

The carcass contributed 74.08% of the moisture, 89.79% of the ether extract, 76.13% of the protein, and 79.11% of the ash to the composition

of the whole animal. Thus, the carcass had the greatest influence on the composition of the live animal. The viscera, contents of the G.I. tract, blood, and hair contributed negligibly to the total ether extract content of the whole animal. The intestines, viscera, contents of the G.I. tract, and blood each contributed about the same amount to the total ash content in the whole animal (about 1.5%). The data also showed that the carcass and head combined, contributed 93.5% of the total ash content of the animal. The carcass, intestines, and head contributed a total of 98.72% to the total ether extract for this group of animals.

The data suggest that the moisture, ether extract, and ash content of the hair could be excluded from the total analysis without introducing much error. However, average values could be used for percent moisture, ether extract, and ash of the hair to further minimize the percentage errors shown in Table III. The protein of hair contributed appreciably to the total protein (3.63%), but an average value could also be used for percent protein since it is the major constituent of hair, scurf, and toenails. Analysis of the blood for ether extract could be disregarded, since it contributed only 0.011% to the total ether extract of the whole animal. The average weight of the contents of the G.I. tract was 3.44 lbs. for this group of animals. Thus, the percentage errors indicated that average values could also be used for percent moisture, ether extract, protein, and ash without introducing an appreciable error. However, this may not be valid if the G.I. contents constituted a greater part of the live weight.

The data showing the various relationships between the carcasses and the whole bodies are given in Appendix Tables 11 through 13. The correlation coefficients between the various carcass and body parameters are

given in Table I. The percent ether extract of the carcass was correlated significantly with that of the empty body (r = 0.991). The following regression equation for estimating percent body ether extract from the percent ether extract of the carcass was derived from the experimental data:

$$\hat{Y} = 0.881X + 0.489, \; S_{x \cdot y} = \pm 0.943\% \qquad (24)$$

This relationship indicated that the ether extract of the carcass can be used as a reliable means for estimating the ether extract content of the body. For instance, if the ether extract content of the carcass were in error by ± 1%, the resulting error for the ether extract content of the body would be about ± 0.88%. The standard error of regression for equation 24 is indicative of this accuracy. From a practical standpoint, equation 24 implies that an accurate estimate of body ether extract can be obtained from an analysis of the carcass only. However, it is possible that this relationship may not be applicable to animals of a different weight range.

Harrington (29) recently reviewed the methods of estimating total body fat from measurements of total body water. A knowledge of total body water can be used to estimate total body fat with considerable accuracy. From the experimental data obtained in this study, the following regression equation was derived for estimating the percent ether extract of the empty body from total body water.

$$\begin{aligned} \hat{Y} &= 97.16 - 1.298X \qquad (25) \\ S_{x \cdot y} &= \pm 0.52\% \\ r_{xy} &= -0.971 \end{aligned}$$

This relationship shows that the degree of accuracy for predicting total body fat is about equal to the degree of accuracy of measuring body water. For instance, a 1% error in measuring body water will result in a 1.3%

error in estimating body fat.

Clawson et al. (30) analyzed the data of previous workers on the chemical composition of the whole empty bodies of 127 pigs ranging in weight from 10 to 350 lbs. and in age from 26 to 300 days. An examination of the data revealed that the percentages of water and fat are highly and inversely correlated (r = -0.98). The data showed a curvilinear relationship according to the following equation:

$$\hat{Y} = 178.83 - 0.63X - 66.62 \log X \text{ , } S_{X \cdot y} = \pm 1.4\%$$
$$X = \text{percent water in whole empty body}$$

From the experimental data obtained in this study, the relationship between the percentages of water and fat in the empty bodies was computed according to equation 26.

$$\hat{Y} = 96.40 - 1.297X \qquad (26)$$
$$S_{X \cdot y} = \pm 1.5\%$$
$$r_{xy} = -0.974$$

A linear relationship was found, since this group of animals was relatively homogenous with respect to age and weight. However, the correlation coefficient obtained between the percentages of fat and water in the empty bodies agreed favorably with that reported by Clawson et al. (30). Likewise, the standard errors of estimate agreed favorably.

Keys and Brozek (31) and Harrington (29) have reviewed the dilution technique of estimating total body fat from the percent water of the fat-free body. The validity of this technique depends upon a non-significant relationship between total body fat and percent water of the fat-free body. The assumption is that the percent water of the chemically mature body is constant, when expressed on a fat-free basis. From the data of Pace and Rathbun (32) on 32 male guinea pigs, Keys and Brozek (31) computed a correlation coefficient of 0.450 between total body fat and percent

water in the fat-free body. Kirton and Barton (33) obtained non-significant, positive relationships between percent water of the fat-free carcass and percent carcass fat of ewes. From the experimental data obtained in the current study, the following equation was derived for predicting percent ether extract of the empty body from the percent water of the ether extract-free, empty body.

$$\hat{Y} = 306.26 - 3.66X \qquad (27)$$
$$S_{x \cdot y} = \pm 2.92\%$$
$$r_{xy} = -0.579$$

The correlation coefficient indicated that the water content of the fat-free, empty body was not independent of ether extract content of the body. The significance of this relationship suggested that the animals used in this study were not chemically mature. This is in agreement with the work of Moulton (34). He stated that the age at which swine attain chemical maturity is between 6 and 12 months. Thus, the validity of estimating body fat from the water content of the fat-free body would be questionable for this group of animals. Also, the magnitude of the standard error would limit the accuracy of predicting body fat from body water. The results obtained by Clawson et al. (30) on the chemical analysis of pigs weighing 225 lbs., showed an inverse relationship between the fat content of the whole body and the water content of the fat-free body. Thus, their work supports the results obtained in the current study.

The percentages of moisture, protein, and ash of the fat-free body and of the fat-free carcass were computed to determine the constancy of the values for this group of animals. The results are summarized in Table IV.

Table IV. Percentages of moisture, protein, and ash in the fat-free body and fat-free carcass

	Fat-free empty body			Fat-free carcass		
	Moisture	Protein	Ash	Moisture	Protein	Ash
Mean	74.51	21.26	4.23	74.17	24.41	4.46
Standard error	0.550	0.481	0.302	0.667	0.533	0.396
Mean*	76.18	19.1	3.84			

*From Mitchell and Hamilton (28).

The means for percent moisture and percent protein between the body and the carcass were not significantly different. The means for percent ash were significantly different at the 5% level. This significance may have been due to the low ash content of the components other than the carcass and head, since they each contributed about 1.5% to the total ash content of the whole animal (Table III). The relationship between the values for percent moisture of the fat-free empty bodies and the fat-free carcasses was highly significant ($r = 0.951$). Likewise, the relationships, with respect to protein and ash, were highly significant ($r = 0.881$ for protein and $r = 0.867$ for ash). The data of Mitchell and Hamilton (28) in Table IV, showed that the moisture content in the fat-free bodies was about 2% higher than the moisture content of the animals used in the current study. Mitchell and Hamilton (28) concluded from their study that the composition of the carcasses was not much different from the composition of the empty bodies. The results of the current study also suggest that the composition of the fat-free carcass can be used to accurately estimate the composition of fat-free body.

The estimation of live animal body composition from carcass composition is of limited value. From a practical standpoint, the composition

of the carcass is the most important economically. Yet, there is little advantage in predicting the composition of the live animal from the carcass, since the animal has already been sacrificed and is no longer available for further experimentation or breeding purposes. Since the composition of the carcass and body is closely related, the most practical way of estimating carcass composition would be from body composition. Thus, from this standpoint, an accurate indirect measure of live body composition would be of great value. The density of a live animal would be such a measure. If the density of an animal could be determined accurately, it could then be used to predict the composition of a live animal and in turn of the dressed carcass.

SUMMARY

The densities obtained on 24 market weight pigs by air displacement were correlated non-significantly with the densities obtained by helium dilution. The densities obtained by each method were correlated non-significantly with percent moisture, ether extract, protein, and ash of the dressed carcasses. Although neither method of measuring body volume was reliable, the helium dilution technique was more closely related to actual body composition than the air displacement technique.

An estimation of errors for the air displacement technique was performed. The greatest source of error appeared to result from inaccuracies in reading relative humidity. Other appreciable sources of error were the uncertainties with which temperature and pressure could be read.

The major difficulties involved in the helium dilution technique were caused by the activity of the experimental animals inside the chamber. The changes in temperature, relative humidity, and the composition of the respiratory gases were the major sources of error.

A chemical analysis of each animal was performed, and the contribution of each component to the composition of the whole animal was presented. Data are presented which show the magnitude of errors resulting from the exclusion of any body compartment, such as blood, hair, or head from the chemical analysis of the whole animal. The data suggested that average values could be used for the composition of many of the minor components without appreciably altering the composition of the total animal.

A regression equation was derived relating the percentages of ether extract in the whole animals and the dressed carcasses. The equation showed that body fat could be estimated from carcass fat with a standard

error of ± 0.943%. Also, a 1% error in carcass fat would result in an error of 0.88% in body fat.

A regression equation for estimating the percent ether extract of the empty bodies from total body water was also presented. The regression coefficient for the relationship was 1.29 and the standard error was ± 0.52%.

A regression equation expressing the relationship between the fat content of the empty bodies and the water content of the fat-free empty bodies was computed. A statistically significant relationship was found ($r = -0.579$). A 1% error in estimating the water content of the fat-free empty bodies resulted in an error of 3.66% for the fat content of the empty bodies. Thus, the validity of estimating body fat from the water content of the fat-free bodies would be questionable for market weight pigs.

LITERATURE CITED

1. Sears, F. W., and M. W. Zemansky. 1957. University Physics. 2nd ed. Addison-Wesley Publishing Co., Inc., Reading, Mass. pp 210-219.

2. Spivak, O. D. 1915. The Specific Gravity of the Human Body. Archiv. Int. Med. 15:628-642.

3. Wedgwood, R. J., J. R. Breckenridge and R. W. Newman. 1953. Measurement of body volume by air displacement. Fed. Proc. 12:151.

4. Pfaundler, M. 1961. Korpermass-Studien an Kinder. IV. Vom Korpervolumen und der Korperdichte. Ztschr. f. Kinderheilk. 14:123.

5. Murlin, J. and B. R. Hoobler. 1913. The energy metabolism of normal and Marasmic children with special reference to the specific gravity of the child's body. Proc. Soc. Exper. Biol. Med. 11:115-116.

6. Pfleiderer, H. 1929. Methodik der Bestimmung dis spezifischen Gewichts am Libenden (Antropopyknometrie). Klin. Wschr. 49:2191-2193.

7. Kohlrausch, W. 1929. Methodik zur quantitativen Bestimmung der Korperstoffe in vivo. Arbeitsphysiol. 2:23-45.

8. Kohlrausch, W. 1929. Zur Kenntnis des Trainingszustandes. Arbeitsphysiol. 2:46-60.

9. Bohnenkanp, H. and J. Schmah. 1931. Untersuchungen zu den Grundlagen des Energie-und Stoffwechsells. IV. Mitteilung. Das Reinvolumen sowie die spezifische Dichte des Menchen und die Bestimmungsweise dieser Grossen. Pfluger's Archiv. 228:100-124.

10. Noyons, A. K. M. and J. Jongbloed. 1935. Uber die Bestimmung des wahren Volumens and des spezifischen Gewichtes von Manch und Tier mit Hilfe von Luftdruckveraanderung. Pfluger's Archiv. 235:588-596.

11. Jongbloed, J. and A. K. M. Noyons. 1938. Die Bestimmung des wahren Volumens und des spezifischen Gewichtes von Menschen mittels Luftdruckveraanderung. Pfluger's Archiv. 240:197-201.

12. Wedgwood, R. J. and R. W. Newman. 1953. Measurement of body fat by air displacement. Amer. J. Phys. Antropol. 11:260.

13. Liuzzo, J. A., E. P. Reineke and A. M. Pearson. 1958. An air displacement method for determining specific gravity. J. Ani. Sci. 17:513-520.

14. Gnaedinger, R. H. 1960. Comparison of air and water displacement for measuring the specific gravity of the human body. M.S. Thesis. Michigan State University.

15. Walser, M. and S. N. Stein. 1953. Determination of specific gravity of intact animals by helium: comparison with water displacement. Proc. Soc. Expt. Biol. Med. 82:774-777.

16. Siri, W. E. 1955. Apparatus for Measuring Human Body Volume. Rev. Sci. Instr. 27:729-738.

17. Morales, M. F., E. N. Rathbun, R. E. Smith and N. Pace. 1945. Studies on body composition. II. Theoretical considerations regarding the major body tissue components, with suggestions for application to men. J. Biol. Chem. 158:677-684.

18. Rathbun, E. N., and N. Pace. 1945. Studies on body composition. I. The determination of total body fat by means of the body specific gravity. J. Biol. Chem. 158:667-676.

19. Pitts, G. C. 1956. Body fat accumulation in the guinea pig. Amer. J. Physiol. 185:41-48.

20. Hodgman, C. D. 1958. Handbook of Chemistry and Physics. 39th ed. Chemical Rubber Publishing Co. Cleveland, Ohio. p. 1404.

21. Behnke, A. R. Jr., B. G. Feen, and W. C. Welham. 1942. The specific gravity of healthy men. J. Amer. Med. Assoc. 118:495-498.

22. Messinger, W. J. and J. M. Stelle. 1949. Relationship of body specific gravity to body fat and water content. Proc. Expt. Biol. Med. 70:316-318.

23. Kraybill, H. F., H. I. Bitter and O. G. Hankins. 1952. Body composition of cattle. II. Determination of fat and water content from measurement of body specific gravity. J. Applied Physiol. 4:575-583.

24. Kraybill, H. F., E. R. Goode, R. S. B. Robertson and H. S. Sloane. 1953. In vivo measurement of body fat and body water in swine. J. Applied Physiol. 6:27-32.

25. Siri, W. E. 1953. Fat, water and lean tissue studies. Fed. Proc. 12:133.

26. Benne, E. J., N. H. Van Hall, A. M. Pearson. 1956. Analysis of fresh meat. J.A.O.C. 39:937-945.

27. Hall, J. L. 1953. Ether extraction method of estimating degree of fatness in carcasses and cuts. Proc. 6th Reciprocal Meats Conference. p. 122-126.

28. Mitchell, H. H., and T. S. Hamilton. 1929. Swine type studies. III. The energy and protein requirements of growing swine and the utilization of feed energy in growth. Univ. of Ill. Agre. Expt. Sta. Bull. 323.

29. Harrington, G. 1958. Pig Carcass Evaluation. Commonwealth Agricultural Bureaux. Farnham Royal, Bucks, England.

30. Clawson, A. J., B. E. Sheffy, and J. T. Reid. 1955. Some effects of feeding chlortetracycline upon the carcass characteristics and the body composition of swine and a scheme for the resolution of the body composition. J. Ani. Sci. 14:1122-1132.

31. Keys, A., and J. Brozek. 1953. Body fat in adult man. Physiol. Rev. 33:245-325.

32. Pace, N. and E. N. Rathbun. 1945. Studies on body composition. III. The body water and chemically combined nitrogen content in relation to fat content. J. Biol. Chem. 158:685-691.

33. Kirton, A. H., and R. A. Barton. 1958. Live weight loss and its components in Romney ewes subjected to L-thyroxine therapy and a low plane of nutrition. I. Effects of live weight, carcass weight and carcass composition. J. Agri. Sci. 51:265-281.

34. Moulton, C. R. 1923. Age and chemical development in mammals. J. Biol. Chem. 57:79.

APPENDIX

Table 1. Summary of body weight and density values

Pig No.	Live weight		Live body density		
	lbs	kgs	Air displacement	Helium dilution	Theoretical
1	205.0	93.0	1.020	--	1.033
2	196.0	88.9	1.066	--	1.037
3	193.0	87.5	1.029	--	1.035
4	220.0	99.8	1.031	--	1.031
5	210.0	95.3	1.056	--	1.015
6	183.0	83.0	1.106	--	1.042
7	203.0	92.1	1.059	--	1.026
8	206.0	93.4	1.066	--	1.038
9	198.0	89.8	1.024	--	1.030
10	211.0	95.7	1.023	--	1.027
11	205.0	93.0	0.975	1.031	1.034
12	186.0	84.4	1.023	0.960	1.033
13	199.0	90.3	1.002	1.078	1.034
14	184.0	83.5	1.004	1.009	1.031
15	181.0	82.1	1.094	1.114	1.031
16	200.0	90.7	1.153	1.043	1.041
17	198.0	89.8	1.080	1.066	1.018
18	209.0	94.8	1.165	1.055	1.030
19	216.0	98.0	1.222	0.997	1.035
20	201.0	91.2	1.221	0.955	1.025
21	181.0	82.1	1.111	1.063	1.037
22	206.0	93.4	1.065	0.940	1.031
23	188.0	85.3	1.103	0.961	1.021
24	182.0	82.6	1.091	0.963	1.025
Mean	198.4	89.99	1.0745	1.0168	1.0308

Table 2. Weights of various frozen body components, hot dressed carcass, and live animal

Pig No.	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails	Hot dressed carcass	Live weight
1*	139.6	10.8	7.6	4.0	8.5	7.9	23.4	140.6	205
2	151.0	9.7	6.9	3.6	10.1	7.2	1.5	156.5	196
3	150.0	12.9	6.5		9.7	8.3	1.0	154.2	193
4	169.6	12.2	8.9	3.9	10.5	7.8	1.1	173.6	220
5	161.5	10.0	7.8	2.3	13.0	7.4	1.4	166.4	210
6	137.7	9.2	7.4	4.4	9.5	9.4	1.0	141.2	183
7	153.3	10.8	8.1	4.3	10.0	7.6	1.1	158.6	203
8	152.4	12.0	9.0	4.0	11.7	8.9	1.4	157.6	206
9	152.4	10.1	8.1	2.1	11.6	7.0	1.0	157.2	198
10	157.9	11.2	8.7	3.2	12.7	9.4	1.2	163.3	211
11	155.8	11.0	7.7	2.5	11.1	8.3	1.5	162.0	205
12	141.1	9.7	7.7	3.7	9.6	8.2	1.1	145.7	186
13	155.2	8.9	7.8	2.3	10.3	6.5	1.0	159.7	199
14	143.7	9.7	7.3	4.3	8.3	4.2	0.9	147.3	184
15	136.0	10.1	7.0	3.2	10.4	7.5	1.0	140.2	181
16	151.1	11.0	8.1	3.4	9.6	9.8	1.0	163.8	200
17	154.3	9.9	7.1	3.2	9.7	6.7	0.8	159.6	198
18	162.5	9.0	8.5	3.9	9.9	8.2	1.0	167.1	209
19	163.9	11.7	9.0	4.2	10.7	6.8	1.0	168.9	216
20	152.7	12.1	8.1	5.4	10.9	7.7	1.0	157.3	201
21	140.3	8.7	6.8	3.1	9.4	6.3	1.3	144.5	181
22	160.1	10.9	8.0	3.0	9.8	7.0	1.2	165.5	206
23	146.9	10.2	7.3	3.5	8.8	5.4	1.0	150.8	188
24	142.7	9.0	7.6	1.7	8.9	6.2	0.9	146.3	182
Total	3631.7	250.8	187.0	79.2	244.7	179.7	25.4	3747.9	4761.0
Mean	151.32	10.45	7.79	3.44	10.20	7.49	1.10	156.16	198.4

*Pig No. 1 was skinned.

Table 3. Percent moisture of animal body components (frozen)

Pig No.	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	46.62	58.41	72.03	81.36	52.63	79.75	38.18
2	46.40	64.02	74.59	79.43	55.08	80.80	8.25
3	46.36	61.80	74.24	---	55.84	83.20	8.25
4	44.42	56.96	73.36	79.73	51.80	81.31	8.25
5	36.44	53.30	70.40	75.98	46.84	79.75	8.25
6	48.21	61.42	75.14	78.53	54.35	79.75	8.25
7	41.74	55.03	74.14	77.63	47.93	78.67	8.25
8	47.17	48.49	72.98	76.75	52.30	78.71	8.25
9	44.18	50.00	72.44	78.09	48.49	79.53	8.25
10	41.69	60.09	74.90	76.95	48.78	80.11	8.25
11	44.75	55.80	73.10	83.62	50.93	77.33	8.25
12	45.76	57.14	71.44	81.69	47.56	79.08	8.25
13	46.09	51.86	71.36	79.82	53.50	79.75	8.25
14	45.49	55.76	72.77	78.43	54.59	79.75	8.25
15	45.24	51.32	71.89	80.40	52.59	77.96	8.25
16	47.28	59.06	72.94	78.10	50.08	79.31	8.25
17	37.98	56.93	73.26	77.47	49.12	78.66	8.25
18	44.08	56.78	74.26	79.30	50.42	80.10	8.25
19	45.17	61.19	73.27	79.56	50.08	82.34	8.25
20	41.34	53.35	72.70	80.27	50.80	78.77	8.25
21	47.27	59.60	73.80	82.86	53.30	79.75	8.25
22	44.35	53.17	74.34	81.83	51.48	79.26	8.25
23	40.12	51.33	71.16	78.78	49.06	78.96	8.25
24	42.32	55.80	72.83	79.88	52.44	81.36	8.25
Total	1060.47	1348.61	1753.34	1826.46	1229.99	1913.96	189.75
Mean	44.19	56.19	73.06	79.41	51.25	79.75	8.25

Table 4. Percent ether extract of animal body components (frozen)

Pig No.	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	35.89	28.62	7.15	1.97	18.02	0.10	44.40
2	35.86	22.52	6.67	2.37	18.33	0.09	1.91
3	35.78	25.17	6.77	--	19.47	0.10	1.91
4	38.70	30.83	8.19	3.65	23.23	0.06	1.91
5	48.26	35.41	10.02	7.57	30.00	0.10	1.91
6	32.70	26.23	7.18	3.22	20.48	0.10	1.91
7	42.02	33.15	6.59	3.99	28.39	0.08	1.91
8	33.94	41.52	9.13	3.75	21.99	0.11	1.91
9	37.98	39.68	10.64	4.77	26.22	0.09	1.91
10	42.13	27.34	6.98	3.96	26.34	0.04	1.91
11	37.15	31.77	7.35	1.22	22.24	0.06	1.91
12	36.91	30.47	10.19	2.26	34.80	0.05	1.91
13	36.37	35.72	8.92	4.78	19.24	0.10	1.91
14	38.27	30.18	5.18	3.19	20.66	0.10	1.91
15	38.30	36.02	7.34	3.82	25.26	0.20	1.91
16	32.82	25.94	6.44	5.93	30.03	0.10	1.91
17	46.86	31.27	7.75	10.62	26.10	0.12	1.91
18	39.08	31.65	7.85	3.80	25.52	0.10	1.91
19	36.62	25.52	8.33	3.56	30.03	0.21	1.91
20	41.74	35.59	8.76	2.61	30.03	0.06	1.91
21	34.78	28.19	6.34	3.30	19.47	0.10	1.91
22	38.09	36.49	7.67	2.72	23.24	0.08	1.91
23	43.78	36.88	9.88	3.26	27.24	0.13	1.91
24	41.63	32.46	8.08	4.34	26.07	0.12	1.91
Total	925.66	758.62	189.40	90.66	592.40	2.40	43.93
Mean	38.57	31.61	7.89	3.94	24.68	0.10	1.91

Table 5. Percent protein of animal body components (frozen)

Pig No.	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	13.88	11.00	17.31	5.06	16.69	18.94	16.50
2	13.50	12.13	16.56	6.69	15.94	17.25	89.00
3	13.63	9.75	16.13	--	15.63	15.06	89.00
4	13.13	9.75	16.00	7.88	14.88	19.25	89.00
5	12.38	10.63	16.44	7.94	13.50	18.94	89.00
6	14.56	11.31	15.50	6.50	15.44	18.94	89.00
7	13.44	9.69	15.81	6.13	14.94	19.25	89.00
8	14.81	8.38	15.06	6.38	15.06	19.13	89.00
9	13.88	8.88	14.19	8.19	15.19	19.00	89.00
10	12.88	11.13	15.94	7.94	13.56	18.13	89.00
11	14.25	10.38	16.44	9.00	16.00	19.44	89.00
12	13.81	10.88	15.75	7.75	13.94	19.63	89.00
13	13.94	9.38	15.81	8.50	16.06	18.94	89.00
14	13.69	10.31	16.25	9.94	15.38	18.94	89.00
15	14.00	9.75	16.06	6.19	14.50	20.19	89.00
16	14.43	10.63	15.38	6.44	14.06	18.38	89.00
17	12.31	10.31	15.44	6.56	14.06	18.69	89.00
18	13.13	10.19	15.00	6.63	14.25	19.06	89.00
19	14.00	11.13	15.31	7.75	14.06	20.31	89.00
20	12.69	9.69	15.38	8.88	14.06	20.06	89.00
21	13.88	11.44	16.88	8.06	15.69	18.94	89.00
22	13.69	9.00	15.69	6.88	15.69	19.19	89.00
23	13.00	9.94	16.00	7.94	15.00	19.19	89.00
24	13.00	10.44	16.00	8.69	14.25	19.94	89.00
Total	325.91	246.12	380.33	171.92	357.83	454.79	2047.00
Mean	13.58	10.26	15.85	7.47	14.91	18.95	89.00

Table 6. Percent ash of animal body components (frozen)

Pig No.	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	3.27	0.88	1.27	2.05	10.22	1.20	0.92
2	2.61	0.99	1.16	2.41	9.07	1.20	1.31
3	2.69	1.08	1.19	--	7.71	1.20	1.31
4	2.80	0.87	1.17	2.08	8.49	1.20	1.31
5	2.05	0.81	1.22	2.24	7.38	1.20	1.31
6	3.18	0.88	1.13	2.09	8.38	1.20	1.31
7	2.81	0.78	1.11	1.91	7.12	1.15	1.31
8	3.29	0.68	1.14	1.76	8.68	1.20	1.31
9	2.71	0.71	1.20	2.40	8.03	1.18	1.31
10	2.81	0.91	1.17	2.84	8.96	1.22	1.31
11	2.38	0.85	1.19	2.24	9.01	1.27	1.31
12	2.68	0.83	1.15	1.83	3.42	1.15	1.31
13	2.94	0.77	1.09	2.20	8.90	1.20	1.31
14	2.55	0.87	1.17	2.09	8.34	1.20	1.31
15	2.84	0.83	1.21	1.72	5.73	1.25	1.31
16	3.00	0.93	1.17	2.84	4.58	1.25	1.31
17	2.69	0.82	1.13	1.64	8.93	1.45	1.31
18	2.99	0.90	1.11	2.20	8.36	1.51	1.31
19	2.95	0.88	1.13	1.94	4.58	1.11	1.31
20	3.07	0.80	1.09	2.04	4.58	1.11	1.31
21	2.71	0.85	1.17	1.56	9.38	1.20	1.31
22	2.91	0.77	1.13	1.83	8.85	1.50	1.31
23	3.06	0.75	1.16	2.17	7.74	1.06	1.31
24	2.82	0.79	1.13	1.70	6.74	1.08	1.31
Total	67.81	20.23	27.79	47.78	183.18	29.29	30.13
Mean	2.83	0.84	1.16	2.08	7.63	1.22	1.31

Table 7. Percent moisture contributed by each component to total body moisture

Pig No.	lbs Total moisture	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	100.98	65.44	6.25	5.42	3.39	4.43	6.24	8.84
2	101.28	74.61	5.08	5.08	2.82	5.49	5.75	0.120
3	98.95	74.52	8.05	4.88	--	5.48	6.98	0.083
4	107.80	73.60	6.45	6.06	2.88	5.05	5.88	0.084
5	88.43	72.09	6.03	6.21	1.98	6.89	6.67	0.131
6	97.30	78.98	5.81	5.71	3.56	5.30	7.71	0.085
7	95.44	72.60	6.22	6.30	3.50	5.02	6.27	0.095
8	105.80	72.86	5.50	6.21	2.90	5.78	6.63	0.109
9	95.96	75.17	5.26	6.12	1.71	5.86	5.80	0.086
10	100.77	70.69	6.68	6.47	2.44	6.15	7.47	0.098
11	101.97	74.45	6.02	5.52	2.05	5.54	6.30	0.121
12	94.37	73.30	5.87	5.83	3.20	4.84	6.87	0.096
13	98.83	76.93	4.67	5.64	1.86	5.58	5.24	0.083
14	91.01	75.78	5.94	5.83	3.70	4.98	3.68	0.081
15	89.91	73.11	5.76	5.59	2.86	6.08	6.51	0.092
16	103.67	73.25	6.27	5.70	2.57	4.64	7.49	0.080
17	87.32	73.18	6.46	5.96	2.84	5.45	6.04	0.075
18	102.38	74.46	4.99	6.16	3.02	4.87	6.42	0.081
19	107.16	73.66	6.68	6.15	3.12	5.00	5.23	0.077
20	97.10	70.78	6.65	6.07	4.46	5.71	6.25	0.085
21	93.44	75.47	5.55	5.37	2.75	5.36	5.37	0.114
22	101.31	75.41	5.73	5.87	2.43	4.98	5.48	0.097
23	84.69	74.20	6.19	6.13	3.26	5.10	5.03	0.098
24	85.69	74.68	5.86	6.47	1.59	5.45	5.88	0.086
Mean		74.077	5.999	5.865	2.821	5.376	6.133	0.0938
Standard error		1.800	0.678	0.402	0.679	0.535	0.890	0.015

Table 8. Percent ether extract contributed by each component to total body ether extract

Pig No.	Total ether extract	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
	lbs.							
1	65.74	76.21	4.70	0.82	0.12	2.33	0.012	15.80
2	58.77	92.14	3.71	0.78	0.15	3.15	0.010	0.049
3	59.28	90.54	5.48	0.74	--	3.19	0.013	0.032
4	72.74	90.24	5.17	1.00	0.19	3.35	0.006	0.028
5	86.37	90.24	4.10	0.90	0.20	4.52	0.008	0.031
6	50.09	89.90	4.81	1.06	0.28	3.89	0.017	0.037
7	71.57	90.01	5.00	0.74	0.24	3.97	0.008	0.029
8	60.28	85.80	8.26	1.36	0.25	4.26	0.016	0.044
9	65.92	87.80	6.08	1.30	0.15	4.61	0.009	0.028
10	73.69	90.27	4.15	0.83	0.18	4.55	0.005	0.031
11	64.48	89.76	5.41	0.88	0.05	3.83	0.007	0.044
12	59.26	87.88	4.99	1.32	0.13	5.64	0.006	0.035
13	62.45	90.39	5.09	1.12	0.18	3.17	0.011	0.030
14	60.17	91.39	4.87	0.63	0.23	2.84	0.006	0.028
15	59.03	88.24	6.17	0.86	0.20	4.46	0.025	0.032
16	56.07	88.44	5.08	0.93	0.36	5.14	0.017	0.033
17	78.86	91.69	3.93	0.70	0.43	3.21	0.010	0.019
18	69.74	91.07	4.09	0.96	0.22	3.63	0.011	0.027
19	67.12	89.38	4.45	1.12	0.22	4.78	0.020	0.028
20	72.20	88.28	5.97	0.98	0.19	4.53	0.006	0.026
21	53.64	90.98	4.57	0.80	0.19	3.41	0.011	0.046
22	67.96	89.73	5.86	0.90	0.12	3.35	0.008	0.033
23	71.33	90.16	5.27	1.01	0.15	3.36	0.009	0.026
24	65.36	90.90	4.47	0.93	0.11	3.55	0.011	0.026
Mean		89.793	5.070	0.945	0.197	3.863	0.0109	0.0323
Standard error		1.444	0.943	0.184	0.0801	0.776	0.0050	0.0072

Table 9. Percent protein contributed by each component to total body protein

Pig No.	lbs. Total protein	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	28.88	67.11	4.12	4.57	0.73	4.92	5.19	13.37
2	27.14	75.13	4.35	4.20	0.88	5.93	5.57	4.94
3	26.42	77.40	4.77	3.97	--	5.75	4.73	3.37
4	29.23	76.19	4.07	4.86	1.06	5.34	5.13	3.35
5	26.92	74.26	3.94	4.75	0.67	6.54	5.20	4.64
6	26.67	75.18	3.90	4.31	1.09	5.51	6.67	3.34
7	27.12	75.96	3.87	4.72	0.96	5.49	5.38	3.61
8	29.91	75.46	3.38	4.55	0.87	5.88	5.68	4.18
9	27.35	77.33	3.29	4.20	0.62	6.44	4.86	3.25
10	27.72	73.38	4.51	5.01	0.90	6.20	6.13	3.86
11	29.57	75.08	3.86	4.29	0.78	6.05	5.44	4.53
12	25.98	75.02	4.08	4.66	1.12	5.16	6.20	3.77
13	27.66	78.20	3.00	4.45	0.72	5.97	3.00	3.22
14	25.17	78.15	3.97	4.73	1.71	5.09	3.18	3.18
15	25.25	75.41	3.88	4.44	0.79	5.98	5.98	3.52
16	28.48	76.54	4.11	4.39	0.77	4.74	6.32	3.13
17	24.63	77.10	4.14	4.43	0.85	5.52	5.08	2.88
18	27.66	77.15	3.33	4.63	0.94	5.10	5.64	3.22
19	29.73	77.19	4.37	4.64	1.11	5.05	4.64	2.99
20	26.24	73.86	4.46	4.76	1.83	5.83	5.87	3.39
21	25.69	75.79	3.89	4.48	0.97	5.72	4.63	4.52
22	28.32	77.40	3.46	4.45	0.74	5.44	4.73	3.78
23	24.81	76.99	4.07	4.72	1.13	5.32	4.19	3.59
24	24.16	76.78	3.89	5.05	0.62	5.26	5.09	3.31
Mean		76.128	3.946	4.553	0.950	5.593	5.189	3.633
Standard error		1.302	0.410	0.253	0.297	0.467	0.870	0.553

Table 10. Percent ash contributed by each component to total body ash

Pig No.	lbs. Total ash	Dressed carcass	Stomach caul fat intestines	Kidneys-spleen esophagus-trachea liver-lungs-heart	Intestinal contents	Head tongue	Blood	Hair scurf toenails
1	6.03	75.62	1.66	1.66	1.49	14.43	1.58	3.65
2	5.24	75.19	1.91	1.53	1.72	17.56	1.64	0.38
3	5.12	78.91	2.73	1.56	--	14.65	1.95	0.25
4	6.03	78.77	1.82	1.66	1.33	14.76	1.56	0.23
5	4.61	71.80	1.74	2.17	1.08	20.82	1.93	0.39
6	5.55	78.92	1.44	1.44	1.62	14.41	2.04	0.23
7	5.37	80.26	1.49	1.68	1.49	13.22	1.62	0.26
8	6.41	78.16	1.25	1.56	1.09	15.91	1.67	0.28
9	5.37	76.91	1.30	1.86	0.93	17.32	1.55	0.24
10	6.01	73.88	1.66	1.83	1.50	18.97	1.91	0.27
11	5.08	73.03	1.77	1.77	1.18	19.69	2.07	0.39
12	4.45	84.94	1.80	2.02	1.57	7.42	2.11	0.31
13	5.78	78.89	1.21	1.56	0.87	15.92	1.35	0.22
14	4.67	78.37	1.71	1.93	1.93	14.78	1.07	0.26
15	4.78	80.75	1.67	1.67	1.26	12.55	1.97	0.27
16	5.39	84.04	1.86	1.67	1.86	8.16	2.28	0.24
17	5.34	77.72	1.50	1.50	0.94	16.29	1.82	0.19
18	6.08	79.93	1.32	1.48	1.48	13.65	2.04	0.21
19	5.70	84.91	1.75	1.75	1.40	8.60	1.32	0.23
20	5.59	83.90	1.79	1.61	1.97	8.94	1.52	0.23
21	4.98	76.31	1.41	1.61	1.00	17.67	1.53	0.34
22	5.85	79.66	1.37	1.54	1.03	14.87	1.26	0.27
23	5.49	81.97	1.46	1.46	1.46	12.39	1.04	0.24
24	4.89	82.21	1.43	1.84	0.63	12.27	1.37	0.25
Mean		79.106	1.627	1.682	1.340	14.385	1.675	0.269
Standard error		3.533	0.308	0.181	0.351	3.494	0.331	0.055

Table 11. Composition of ether extract-free, contents-free body and ether extract-free carcass

Pig No.	Ether extract-free, contents-free body				Ether extract-free carcass			
	Weight	% moisture	% protein	% ash	Weight	% moisture	% protein	% ash
1	131.39	73.66	21.82	4.52	90.02	73.41	21.53	5.07
2	130.47	75.43	20.62	3.95	99.89	75.64	20.41	3.94
3	--	--	--	--	--	--	--	--
4	139.56	75.01	20.72	4.26	106.36	74.60	20.94	4.47
5	117.98	73.47	22.66	3.87	87.05	73.23	22.96	3.80
6	125.68	74.67	20.99	4.34	94.32	74.10	21.26	4.64
7	124.35	74.07	21.68	4.26	94.20	73.56	21.87	4.58
8	138.72	74.06	21.37	4.57	104.67	73.65	21.56	4.79
9	126.82	74.37	21.43	4.19	96.41	74.82	21.94	4.28
10	131.70	74.65	20.86	4.50	96.01	74.19	21.19	4.62
11	134.24	74.40	21.86	3.74	101.83	74.56	21.80	3.64
12	121.42	75.23	21.16	3.61	92.44	74.83	21.08	4.09
13	130.12	74.57	21.06	4.40	102.22	74.38	21.16	4.46
14	116.96	74.93	21.15	3.92	92.30	74.72	21.31	3.97
15	117.11	74.58	21.39	4.03	88.63	74.16	21.48	4.36
16	134.56	75.07	21.00	3.93	102.27	74.25	21.32	4.43
17	114.55	74.06	21.32	4.62	87.04	73.41	21.82	4.77
18	132.68	74.83	20.65	4.51	102.43	74.42	20.83	4.74
19	138.84	74.78	21.18	4.05	106.72	73.96	21.50	4.54
20	124.01	74.81	20.77	4.42	92.80	74.06	20.88	5.05
21	121.24	74.95	20.98	4.07	93.79	75.19	20.76	4.05
22	132.75	74.46	21.18	4.36	102.98	74.19	21.29	4.53
23	111.87	73.24	21.93	4.84	86.44	72.70	22.10	5.21
24	113.20	74.50	21.21	4.29	86.56	73.91	21.43	4.64
Mean		74.513	21.260	4.228		74.171	21.410	4.464
Standard error		0.550	0.481	0.302		0.667	0.533	0.396

Table 12. Percentage composition of whole animal and hot dressed carcass

Pig No.	Whole body								Hot dressed carcass			
	Moisture		Ether extract		Protein		Ash					
	+Co*	-Co	+Co	-Co	+Co	-Co	+Co	-Co	Moisture	Ether extract	Protein	Ash
1	49.26	48.20	32.07	32.70	14.09	14.28	2.94	2.96	47.00	35.63	13.78	3.24
2	51.67	51.15	29.98	30.50	13.84	13.98	2.67	2.68	48.28	34.60	13.03	2.52
3	51.27	51.27	30.72	30.72	13.69	13.69	2.65	2.65	47.82	34.81	13.26	2.62
4	49.00	48.45	33.06	33.60	13.29	13.38	2.74	2.75	45.70	37.81	12.83	2.74
5	42.11	41.73	41.13	41.50	12.82	12.87	2.20	2.20	38.31	46.84	12.01	1.99
6	53.17	52.54	27.37	27.97	14.57	14.77	3.03	3.06	49.50	31.89	14.20	3.10
7	47.01	46.35	35.26	35.93	13.41	13.57	2.65	2.66	43.69	40.62	12.99	2.72
8	51.48	50.98	29.33	29.84	14.55	14.71	3.12	3.15	48.91	32.82	14.32	3.18
9	48.46	48.15	33.29	33.60	13.81	13.87	2.71	2.72	45.88	36.82	13.45	2.63
10	47.76	47.31	34.92	35.40	13.14	13.22	2.85	2.85	43.62	40.73	12.46	2.72
11	49.74	49.32	31.45	31.83	14.42	14.49	2.48	2.48	46.86	35.73	13.70	2.29
12	50.74	50.11	31.86	32.46	13.97	14.09	2.39	2.40	47.47	35.74	13.38	2.59
13	49.74	49.38	31.43	31.74	13.92	13.95	2.91	2.92	47.61	35.35	13.54	2.86
14	49.60	48.91	32.79	33.50	13.72	13.81	2.54	2.56	46.82	37.33	13.35	2.48
15	49.81	49.26	32.70	33.23	13.99	14.13	2.65	2.66	46.88	37.15	13.58	2.77
16	51.84	51.38	28.04	28.40	14.24	14.37	2.70	2.69	48.80	31.87	14.01	2.91
17	44.10	43.55	39.83	40.31	12.44	12.54	2.70	2.72	40.17	45.31	11.90	2.60
18	48.99	48.41	33.37	33.93	13.23	13.36	2.91	2.92	45.62	38.01	12.77	2.91
19	49.61	49.02	31.07	31.62	13.76	13.88	2.64	2.65	46.76	35.54	13.60	2.87
20	48.31	47.43	35.92	36.84	13.05	13.17	2.78	2.80	43.42	40.27	12.24	2.96
21	51.62	51.08	29.64	30.10	14.19	14.30	2.61	2.77	48.80	33.77	13.47	2.63
22	49.18	48.69	32.99	33.44	13.75	13.85	2.84	2.85	46.16	36.85	13.24	2.82
23	45.05	44.41	37.94	38.60	13.20	13.30	2.92	2.93	41.67	42.65	12.67	2.98
24	47.08	46.77	35.91	36.21	13.27	13.32	2.69	2.70	43.74	40.61	12.68	2.75
Mean	49.03	48.49	33.00	33.50	13.69	13.78	2.72	2.74	45.81	37.45	13.19	2.75

*+Co = including contents of G.I. tract
-Co = excluding contents of G.I. tract

Table 13. Length, backfat thickness, and dressing percentage data

Pig No.	Length inches	Backfat thickness inches				Dressing percent
		First rib	Last rib	Last lumbar vertebra	Average	
1	--	-	-	-	-	--
2	--	-	-	-	-	78.3
3	--	1.5	1.0	1.1	1.2	78.3
4	30.8	1.7	1.0	1.3	1.3	77.9
5	29.3	2.5	1.5	1.7	1.9	77.6
6	29.4	1.4	0.9	0.9	1.1	76.0
7	30.4	1.9	1.1	1.3	1.7	76.0
8	30.9	1.5	0.9	1.2	1.2	74.5
9	29.6	1.8	1.1	1.1	1.3	77.5
10	30.8	2.1	0.9	1.5	1.5	75.3
11	28.5	1.9	1.3	1.4	1.5	76.4
12	28.8	1.5	1.0	1.2	1.2	76.0
13	29.9	1.8	1.1	1.3	1.4	78.5
14	28.7	1.5	1.0	1.1	1.2	78.5
15	29.5	1.9	1.0	1.2	1.4	75.7
16	30.5	2.0	0.9	1.0	1.3	76.0
17	29.1	2.2	1.3	1.8	1.8	78.6
18	30.0	2.2	1.4	1.3	1.6	78.1
19	31.2	2.1	1.1	1.2	1.5	76.4
20	29.8	2.8	1.5	1.5	1.9	76.4
21	28.8	2.0	1.1	1.0	1.4	78.2
22	31.1	1.8	1.0	1.2	1.3	78.5
23	28.3	2.0	1.4	1.5	1.6	78.8
24	28.3	1.8	1.1	1.4	1.4	78.9
Mean	29.7	1.90	1.12	1.28	1.44	77.15