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M.A.
1981

This is to certify that the

thesis entitled

THE EFFECTS OF WATER IMMERSION AND LEVEL OF

EXHALATION UPON BODY DENSITY ANALYSIS

presented by

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has been accepted towards fulfillment
of the requirements for

M.A. degree in Physical Education

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Date Aug 13, 1981

O-7639

THE EFFECTS OF WATER IMMERSION AND LEVEL OF EXHALATION UPON BODY DENSITY ANALYSIS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Health, Physical Education and Recreation

1981

ABSTRACT

THE EFFECTS OF WATER IMMERSION AND LEVEL OF EXHALATION UPON BODY DENSITY ANALYSIS

By

Craig S. Vossekuil

The purpose of this study was to determine the effects of immersion in water upon residual volume and body density calculation and to compare the effects of level of exhalation upon body density calculation.

Thirty-five normal, healthy males, 18-28 years of age, served as subjects. A sequence of five measurements of lung volume were determined: predicted residual volume, residual volume in air, residual volume while immersed to the neck in water, and end-tidal volume while fully submerged in water. The underwater weight of each subject was recorded simultaneously with the latter two measurements, and calculations of body density were made for each of the five conditions.

There were statistically significant differences ($p<.01$) between the criterion procedure for measuring body density (exhaling maximally while fully submerged in water) and all other procedures except one: there was no significant difference between the criterion procedure and the procedure using end-tidal lung volume. It is apparent that the determination

of body density using end-tidal lung volume is a valid alternative to the criterion procedure.

To my parents

ACKNOWLEDGMENTS

Were it not for the work of others in generating and transmitting knowledge, the wheel would be continually reinvented: we stand on the shoulders of giants. Among the tallest of these are Dr. W. D. VanHuss and Dr. W. W. Heusner, to whom I am indebted for assisting with this paper and for setting high standards of performance. Thanks also to Mr. Bob Wells for the generous donation of his time, which is limited, and his technical expertise, which is not, and to Bill, Bruce, and Homer for their help in data collection.

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CHAPTER I

INTRODUCTION TO THE PROBLEM

In physiological research concerned with the effects of such variables as exercise and diet, it is often of interest to determine the effects of these stresses on body composition. Measurements of body composition permit the estimation of body fat and fat-free weight. When these components of body composition are in the proper proportion to each other both sports performance and healthful living in general are enhanced.

Obtaining an accurate estimation of body composition is not easily accomplished. The approach most commonly used to obtain such an estimation is hydrostatic weighing. In this method the precision with which one can estimate body composition is dependent upon obtaining accurate measures of underwater body weight and of the residual volume of air in the lungs at the time of weighing. Most underwater weighing systems are suspension systems whereby the subject is lowered underwater by means of a hoist. The subject then exhales maximally, at which time the underwater weight is quickly observed, and the residual volume of air is measured. Care must be taken with this system, however, to obtain the needed accuracy. Water turbulence, pendulum action created by lowering the chair into the water, and movement of the subject in the chair (some of which may be unavoidable due to the necessity for the subject to exhale maximally) can all create sufficient scale oscillations to preclude any reasonable chance of obtaining an accurate reading.

The present study is intended to examine ways of simplifying the measurement of lung volume at the time of underwater weighing, with the goal of reducing operator error associated with body composition measurement. This could conceivably be accomplished in two ways. First, the subject could be allowed to exhale normally to end-tidal volume, rather than exhaling maximally to residual volume. This would minimize movement of the chair and scale oscillation and maximize the time for the operator to evaluate the underwater weight. Second, residual volume could be measured under ordinary environmental conditions (in air) or with the subject immersed in water up to the neck. If one of these measures of residual volume were found to be a sufficiently accurate estimation of residual volume while submerged, it could be used in subsequent calculations of body composition, which would simplify procedures for obtaining a measure of underwater weight.

Few studies have been conducted comparing estimates of body composition using lung volumes following maximal expiration with estimates obtained using lung volumes following partial expiration, and those that have been done show conflicting results. Some show that it makes no difference what volume of air remains in the lungs at the time the underwater weight is observed (4,12); others show body density to be lower at full expiration than at one-half full expiration (19). Similarly, findings differ in studies comparing residual volume measured in air with residual volume measured while immersed. Some investigators found decreases in residual volume when immersed (1,2,11); some found increases (9); some found no difference (3,5,7,15,18); and others have found both increases and decreases depending upon the age of the subject (13). The present study is intended to offer new information in this area.

Purpose of the Study

To determine the effects of immersion in water (either immersion to the neck or full submersion) upon residual volume and to compare the effects of the level of exhalation (either end-tidal or maximal) upon body density calculation.

Research Hypotheses

The present investigation was designed to test the following hypotheses:

1. There is no difference between residual volume measurements made with subjects fully submerged in water and those made under ordinary environmental conditions (in air) or while immersed to the neck.

2. Predicted residual volume, based upon subjects' height, weight, and age, will not differ from residual volume measured with the subjects submerged in water.
3. Body density calculations will not differ, regardless of whether lung volume is measured following maximal or end-tidal exhalation.

Research Plan

Five body density calculations were made on each of 35 subjects using the lung volume taken under the conditions noted below:

1. Residual volume under ordinary environmental conditions (in air).
2. Residual volume while immersed to the neck in water.
3. Residual volume while fully submerged.
4. Predicted residual volume, based on subjects' age, height, and weight.
5. End-tidal volume while fully submerged.

The residual volume was determined using the procedures originally outlined by Lundsgaard and VanSlyke (14), modified by Rahn, Fenn, and Otis (16), and validated further by Sloan and Bredell (18). Body density was calculated as described by Buskirk (4). The Siri formula was used for the determination of percent fat (17). Data analyses were accomplished using dependent t-tests and Pearson product-moment correlations.

Definition of Terms

Residual Volume

The volume of air remaining in the lungs following a maximal exhalation.

Functional Residual Volume

The volume of air remaining in the lung following a normal exhalation (end-tidal volume).

Hydrostatic Weighing

A technique used to determine body composition whereby a subject is weighed while fully submerged in water. Adjustments necessarily must be made in subsequent calculation of body density for the volume of air remaining in the lungs.

Body Composition

The division of body constituents into its components of body fat and lean body mass.

Body Density

A measure of weight per cubic centimeter of the body, which varies with the relative contributions of body fat and lean body mass.

CHAPTER II

REVIEW OF THE LITERATURE

The literature which is related to this study has been subdivided into the following three sections: (a) the effect of water submersion on residual volume, (b) a review of the methods for determining residual volume, and (c) the effect of the level of expiration on body composition measurement.

The Effect of Water Submersion on on Residual Volume

The principle of Archimedes states that a body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body. Because the amount of fluid displaced will vary with the amount of air that is in the lungs, it becomes critical in the calculation of body density to know the volume of air that is in the lungs at the time the underwater weight is recorded.

Accordingly, most investigators obtain a simultaneous measurement of underwater weight and residual volume while the subject is completely submerged in water. Problems with operator error and subject discomfort exist with this method, however, and therefore it is of interest to determine the necessity of obtaining a measurement of residual volume while fully submerged in water vis a vis obtaining that measurement under ordinary environmental conditions (in air) or with the subject immersed to the neck.

Few studies have been conducted comparing residual volume values collected when subjects were fully submerged in water with residual volume values collected in air. Several studies, however, have compared residual volume values in air with those obtained while the subject was immersed in water to the neck, but these studies show conflicting results.

Some investigators have found no significant differences in residual volume when measured in air as when measured with the subject immersed to the neck in water (5,7,15). Sloan and Bredell (18) and Brozek, Henschel, and Keys (3) observed distinct, though not quite significant, decreases in residual volume with subjects immersed to the neck and fully submerged, respectively. Other researchers have found significant decreases in residual volume as a result of immersion to the neck in water (1,2,11). Some report an increase in residual volume (9) or both increases and decreases depending upon the age of the subject (13).

While there has been a lack of uniformity in these findings, most authors are consistent in finding that the magnitude and the direction of the difference between residual volume while immersed and residual volume in air varied considerably between individuals. This suggests that the magnitude and direction of these variations are due to an interplay of factors. As these factors vary in importance between individuals, measured residual volume will be greater or lesser when submerged than when measured in air. Among those suggested are psychological factors, such as fear and apprehension of the subject, which might inhibit exhalation and result in increased residual volume (3); hydrostatic pressure on the chest wall, resulting in greater exhalation and decreased residual volume (3); greater pressure on the lower limbs than on the chest wall, leading to vascular engorgement and stiffness of lung tissue, trapped air in alveoli, and an increased residual volume (9).

A Review of the Methods for Determining Residual Volume

Modifications of two basic methods for indirect measurement of residual volume have been employed in body density research; the open-circuit method originally developed by Darling, Cournand, and Richards (8), and the closed-circuit method reported by Lundsgaard and VanSlyke in 1918 (14).

In the open-circuit approach, the subject inspires pure oxygen for a period of up to seven minutes. The expired air is collected, and when all of the nitrogen has been washed out of the lungs, the volume of expired air is noted, a sample is drawn for analysis, and residual volume is calculated.

The closed-circuit method developed by Lundsgaard and VanSlyke consists of having a subject exhale maximally and then take 4-5 fairly deep respirations from a rubber bag filled with 3-4 liters of oxygen. A percentage equilibrium between the air in the lungs and the air in the bag is reached; a sample from the bag is analyzed for its nitrogen percentage; and the residual volume can then be calculated.

In 1948, Rahn, Fenn, and Otis found that equilibrium is established between the gases in lung and the gases in a 2-liter rebreathing bag after the third breath, rather than the fourth or the fifth (16). Further, they showed that the value for nitrogen content in normal alveolar air prior to the inhalation of oxygen is more properly 80%, rather than 79.1. The present investigation uses the Rahn modification of the Lundsgaard and VanSlyke closed-circuit method. This method has consistently been shown to be highly reliable and valid (18,20,21), and it minimizes the time needed per determination.

The Effect of the Level of Expiration on Body Composition Measurement

Among those factors suggested as reasons for some individuals having smaller residual volumes when submerged, others largers, are psychological factors, viz. anxiety and apprehension while exhaling maximally under water. Although it has been customary that subjects should exhale maximally, the amount of air in the lungs at the time of measurement should theoretically not influence the calculation of body density. That is, as long as the volume of air in the lungs was known, it would be accounted for in the subsequent calculation of body density. If this were indeed the case, it would be possible to eliminate much of the individualistic tendency mentioned above by performing hydrostatic weighing at less than full expiration; the subject would be allowed greater comfort, psychological factors would be minimized, and the operator would have more time to accurately assess the underwater weight.

Buskirk (4) cited Carlson and Chen (unpublished) as finding that as long as residual volume was measured, it made no difference what volume of air remained in the lungs at the moment the underwater weight was observed. Keys and Brozek (12) also found close agreement in body composition at full expiration and at moderate expiration in repeated trials in the same men. Welch and Crisp (19), on the other hand, found body density at full expiration to be lower than at one-half full expiration.

CHAPTER III

RESEARCH METHODS

The present study was undertaken to investigate differences in body density when lung volume is measured as follows: (a) residual volume measured in air, (b) residual volume measured with the subject immersed up to the neck in water, (c) residual volume measured with the subject fully submerged, (d) end-tidal volume measured with the subject fully submerged, and (e) predicted residual volume.

Subjects

Thirty-five normal, healthy males ranging in age from 18-28 years (mean age = 20.9) volunteered as subjects for the study. None was either grossly obese or emaciated.

Measurement Procedures

Underwater Weight

Measurement of underwater weight was made using a suspension system whereby the subject sat in a metal chair that was lowered by a hoist to a depth such that his head was approximately one inch underwater. A Sanborn recorder (Model 60-200), coupled with a Sargent recorder (Model SR), was used to record the output of a 200-lb load capacity strain gauge. The scales were sufficiently damped to eliminate artifact yet retain adequate sensitivity to measure underwater weight within thirty grams. Final calibration of the scales was accomplished by attaching the rebreathing bag assembly to the metal chair, sealing the mouthpiece with tape, submerging the chair to a depth such that a subject would be completely submerged, and then readjusting the zero point on the recorder.

Lung Volume

Ninety-nine point eight percent pure oxygen was passed through a spirometer to saturate the gas with water vapor and to bring it to room temperature and pressure. Then, using a one-liter syringe coupled with a three-way valve, two liters of the gas were withdrawn from the spirometer and introduced into a rebreathing bag assembly. The rebreathing bag assembly was portable and consisted of a mouthpiece and three-way valve, branching off to a breathing tube open to room air and a breathing tube leading to a two-liter rubber rebreathing bag. The dead space in the tubing and three-way valve was determined to be 72.5 ml by means of water displacement. The water displacement method was also used to calibrate the one-liter syringe. The spirometer, connective tubing, syringe, and rebreathing bag were thoroughly flushed with O_2 prior to introducing the O_2 used for determination of lung volume.

After the sample was taken, the rebreathing bag was immediately transported to an adjoining room and analyzed for content of the gas. Determinations of percent CO_2 and O_2

were accomplished simultaneously by using the Beckman LB-2 and OM-11 analyzers, respectively. The percentages were added together and subtracted from 100% to give percent N_2. The gas analyzers were adjusted to the zero points by the use of compressed helium. Using a Haldane chemical analyzer oxygen and carbon dioxide concentrations (20.1% O_2; 4.52% CO_2) of a standard gas sample were determined. In addition a calibrated sample of 99.5% O_2 was used to check the upscale range of the oxygen analyzer.

Test Procedures

A sequence of four measurements of lung volume were taken. Prior to the first measurement, the subject was weighed, and the weight was recorded. The subject then sat in a chair, a nose clip was placed on his nose, and he inserted the mouthpiece of the rebreathing bag assembly into his mouth. The subject was instructed to exhale as forcefully as he could, and this procedure was repeated until it became apparent that the subject had truly made a maximal exhalation; the subject was then considered to be trained and ready to proceed with the determinations of lung volume.

Residual Volume in Air

After successfully performing a maximal exhalation as described above, the subject was instructed to again exhale maximally; upon reaching the point of maximal exhalation, he turned the three-way valve on the rebreathing bag assembly so that he would inhale on the next breath from the rebreathing bag, which had been filled with two liters of O_2. The subject then took three deep breaths. After the third exhalation, the subject turned the three-way valve back to its original position, and the gas in the bag was immediately analyzed for percentage CO_2 and O_2.

Residual Volume While Immersed to the Neck in Water

Following the determination of residual volume in air, the rebreathing bag was flushed three times with O_2 and refilled with two liters of O_2. The rebreathing bag assembly was then attached by a clamp to a metal chair suspended above a swimming pool; the subject sat in the chair and put the mouthpiece of the rebreathing bag assembly in his mouth and the noseclip on his nose. The subject was lowered into the water by a hoist so that his shoulders were approximately one inch underwater. The same procedure was followed as in the preceding determination; the subject exhaled maximally, turned the three-way valve, inhaled and exhaled three times from and into the rebreathing bag filled with O_2, and turned the valve back after the third exhalation. The gas in the bag was analyzed for percentage CO_2 and O_2.

Residual Volume While Fully Submerged in Water

After the rebreathing bag was flushed, refilled with two liters of O_2, and reattached to the metal chair, the chair and subject were lowered into the water so that the subject's head was approximately one inch underwater. The subject was acclimated to breathing underwater until he was able to stay underwater for fifteen seconds without undue stress. The subject was then resubmerged and made four respirations so that a baseline of four respiratory cycles was established on the recorder. The fourth exhalation was maximal and was held for five seconds. The subject turned the three-way valve, inhaled and exhaled three times, and turned the valve back. The gas in the bag was analyzed for percentage CO_2 and O_2, and the underwater weight at the point of the five-second maximal exhalation was noted.

End-Tidal Volume While Fully Submerged in Water

The rebreathing bag was again flushed and refilled with O_2. The subject was resubmerged so that his head was approximately an inch underwater, and he made four respirations to establish a baseline. The fourth exhalation was a normal one and was held for five seconds. The subject turned the three-way valve, inhaled and exhaled three times, and turned the valve back. The gas in the bag was analyzed for percentage CO_2 and O_2, and the underwater weight at the point of the five-second end-tidal exhalation was noted.

Statistical Analysis

Using residual volume while fully submerged, with the underwater weight recorded simultaneously, as the criterion measure, t-tests for dependent samples were conducted comparing other measures of residual volume and percent fat with those collected using the criterion measure. The significance level was set at $p<.01$. Pearson product-moment correlations were also calculated between the criterion measure of percent fat and other measures of percent fat.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this investigation was to study the effects of immersion in water upon residual volume and subsequent calculation of body density and to compare the effects of level of exhalation upon body density calculation. The data are presented in the following order:

a. Predicted residual volume, residual volume measured in air, and residual volume measured with the subject immersed to the neck in water all in comparison with the criterion measure, i.e., residual volume measured with the subject fully immersed in water.

b. Percent fat calculated using predicted residual volume, percent fat calculated using residual volume measured in air, percent fat calculated using residual volume measured with the subject immersed to the neck in water, and percent fat calculated using end-tidal volume all in comparison with percent fat calculated using the criterion measure of residual volume.

Residual Volume

The results for residual volume are presented in Tables 4.1 and 4.2. The differences between the criterion measure and other measures of residual volume were all statistically significant.

Table 4.1.--Statistical Results, Descriptive, Residual Volume.

	RV Predicted	RV In Air	RV Head Out	RV Fully Submerged	End-Tidal Volume Fully Submerged
$\bar{X}$	1972	1426	1371	1205	1680
SD	256	360	327	443	525

Table 4.2.--Statistical Results, Significance, Residual Volume.

	RV Predicted	RV In Air	RV Head Out
RV Fully Submerged (Criterion Measure)	<.01	<.01	<.01

Percent Fat

The results for percent fat are presented in Tables 4.3, 4.4, and 4.5. The only measure of percent fat that was not significantly different from the criterion measure was that calculated from end-tidal volume. In addition, the measure of percent fat calculated from end-tidal volume was highly correlated with the criterion measure.

Table 4.3.--Statistical Results, Descriptive, Percent Fat.

	% Fat Predicted	% Fat In Air	% Fat Head Out	% Fat Fully Submerged	% Fat End-Tidal Volume
$\bar{X}$	9.08	12.51	12.68	13.70	13.81
SD	5.92	5.14	5.51	5.18	5.72

Table 4.4.--Statistical Results, Significance, Percent Fat.

	% Fat Predicted	% Fat In Air	% Fat Head Out	% Fat End-Tidal Volume
% Fat Fully Submerged (Criterion Measure)	<.01	<.01	<.01	.70

Table 4.5.--Correlation, Percent Fat.

	% Fat End-Tidal Volume	% Fat Predicted	% Fat In Air	% Fat Head Out
% Fat Predicted	.822			
% Fat In Air	.886	.883		
% Fat Head Out	.885	.904	.974	
% Fat Fully Submerged (Criterion Measure)	.954	.853	.920	.922

Discussion

It was the intention of this study to determine the effects of variations in methods of measuring lung volume upon the subsequent calculation of body density. The residual volumes of all subjects were measured under three conditions: in air, immersed to the neck, and fully submerged in water. These values, along with predicted residual volume and end-tidal volume were used in separate calculations of body density. Statistical analyses were then made to determine whether or not there were significant differences between methods of measuring residual volume and whether or not these differences in lung volume resulted in significant differences in calculated body density.

At this point it is important to review the hypotheses:

Hypothesis 1: *There is no difference between residual volume measurements made with subjects fully submerged in water (criterion measure) and those made under ordinary environmental conditions (in air) or while immersed to the neck.*

This hypothesis cannot be accepted. There were highly significant differences between the criterion measure of residual volume and those made in air or with the subject immersed to the neck (Table 4.2, $p<.01$). This finding is in the same direction as that of Brozek, Henschel, and Keys (3), who found distinct, though not significant, decreases in residual volume when the subject was fully submerged. The present data tend to show that the further the body is immersed in water, the more the residual volume will decrease.

Hypothesis 2: *Predicted residual volume, based upon subjects' height, weight, and age will not differ from residual volume measured with the subjects submerged in water.*

The data do not support this hypothesis. There is a highly significant statistical difference between the criterion measure of residual volume and predicted residual volume (Table 4.2, $p<.01$).

Hypothesis 3: *Body density calculation will not differ, regardless of whether lung volume is measured following maximal or end-tidal exhalation.*

The data collected in the present study support this hypothesis. No significant difference was found between body density at end-tidal exhalation and body density calculated using the criterion measure, i.e., residual volume while fully submerged (Table 4.4, $p<.70$). These data are at variance with that collected by Welch and Crisp (19), who found body density at full expiration to be lower than at one-half full expiration. The present data are, nevertheless, in agreement with those of Keys and Brozek (12) and Carlson and Chen (unpublished), who found that it made no difference what volume of air remained in the lungs at the moment the underwater weight was observed.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effects of immersion in water upon residual volume and subsequent body density calculation and to compare the effects of level of exhalation upon body density calculation.

Thirty-five normal, healthy males, 18-28 years of age, served as subjects. A sequence of five measurements of lung volume were taken: residual volume in air, residual volume while immersed to the neck in water, predicted residual volume, residual volume while fully submerged in water, and end-tidal volume while fully submerged in water. In addition, the underwater weight of each subject was recorded simultaneously with the latter two measurements. Calculations of body density were then made. The criterion measure, residual volume while fully submerged, was compared to the other measures of residual volume; similarly, the criterion procedure for measuring body density, based on residual volume measured with the subject fully submerged, was compared to the other procedures for measuring body density. Data analysis was accomplished by the use of dependent t-tests and correlation.

There were statistically significant differences between the criterion measure of residual volume and all other measures. Significant differences were also detected between the criterion measure of body density and all other measures of body density except one: there was no significant difference between the criterion procedure for calculating body density and the procedure for calculating body density using end-tidal lung volume.

Conclusions

1. There was a significant difference between residual volume measured with the subject fully submerged and residual volume measured under ordinary environmental conditions or with the subject immersed to the neck.
2. There was a significant difference between predicted residual volume and the criterion measure of residual volume.
3. There was a significant difference between body density measures based on the criterion measure of residual volume and those measures of body density based on other measures of residual volume.
4. There was no statistically significant difference between the criterion measure of body density and the measure of body density based on end-tidal volume. With a correlation between these two measures of

.954, it is apparent that the determination of body density using end-tidal lung volume is a valid alternative to the criterion procedure.

Recommendations

1. Further studies should be made to test the reliability of the end-tidal procedure in comparison with the reliability of the criterion procedure for measurement of body density.
2. In further studies of this nature, duplicate determinations should be made.

APPENDICES

APPENDIX A

BASIC DATA

APPENDIX A

BASIC DATA

	% Fat Predicted 1	% Fat In Air 2	% Fat Head Out 3	% Fat Fully Submerged 4	% Fat End-Tidal Volume 5	RV Predicted 1	RV In Air 2	RV Head Out 3	RV Fully Submerged 4	End-Tidal Volume 5
1. T.T.	6.22	12.0	12.6	13.9	15.2	2680	1869	1794	1566	2169
2. J.Z	13.9	18.3	18.3	15.7	19.3	2049	1255	1189	604	1674
3. M.B.	4.5	10.0	7.9	9.2	6.2	2009	1171	1398	1209	2566
4. R. O.	23.7	26.9	28.7	27.3	28.7	2075	1568	1241	1505	1582
5. D. G.	12.8	17.2	15.7	19.0	18.8	2186	1422	1374	1094	1680
6. C. L.	4.1	5.4	4.5	7.5	5.8	2138	972	1085	745	914
7. T. M.	10.0	15.2	16.1	15.7	17.0	2103	1277	1194	1242	1167
8. S. G.	7.1	14.4	13.5	10.5	9.2	2262	1189	1292	1790	2611
9. K. L.	14.8	12.2	14.4	9.6	8.8	1798	2196	1807	2684	3104
10. R. M.	7.5	7.5	7.1	11.8	12.7	2011	2019	2071	1334	2191
11. A. L.	5.8	8.3	8.8	10.9	10.0	1996	1611	1536	1200	1702
12. J. E.	11.8	11.3	14.3	10.5	10.0	1937	1993	1560	2131	2077
13. C. L.	4.5	7.9	7.1	10.0	9.6	1862	1342	1479	931	1394
14. D. D.	10.5	10.5	9.6	11.3	13.0	1853	1884	1963	1662	1963
15. C. L.	12.6	14.8	16.1	17.0	17.0	2004	1652	1423	1290	1439
16. B. D.	2.5	8.3	7.5	9.2	8.8	1952	1199	1290	1050	1931
17. C. G.	11.3	12.2	11.8	14.4	13.9	1827	1687	1741	1370	1768
18. D. V.	9.6	16.1	17.0	21.4	21.4	2077	1185	1027	415	1276
19. M. T.	18.3	18.3	17.9	20.9	22.7	1627	1657	1682	1091	1781
20. M. A.	2.5	9.6	8.8	10.9	9.2	2173	1180	1307	1019	2004
21. B. K.	2.5	5.8	5.8	6.6	5.0	2069	1505	1560	1405	2077
22. M. D.	5.4	10.9	9.2	9.2	8.3	1854	1175	1276	1269	1526
23. S. L.	2.9	10.5	9.2	11.8	13.5	1809	787	711	604	1023
24. S. J.	-0.8	8.3	8.3	8.3	8.7	2317	1490	1465	1373	1905
25. D. H.	18.3	19.2	21.0	21.9	21.4	1449	1047	1065	916	1216
26. C. R.	0.0	5.0	4.5	5.8	7.1	2084	1223	1294	1084	1381
27. B. P.	8.2	12.2	13.0	14.4	13.9	2220	1612	1442	1279	1198
28. B. S.	0.0	8.8	9.6	10.5	10.9	2173	871	764	659	1023
29. A. G.	11.3	11.8	13.0	15.7	12.2	2254	2138	1893	1502	2382
30. J. M.	6.2	6.6	8.3	10.0	13.5	1695	1633	1430	1182	1372
31. B. M.	13.5	16.5	15.7	16.5	21.0	1780	1322	1463	1292	1084
32. E. E.	9.2	13.0	14.8	14.8	13.9	1776	1088	728	758	1953
33. K. K.	21.4	26.0	25.5	25.0	23.7	1883	1183	1154	1252	1626
34. M. V.	11.8	12.6	14.8	17.4	16.9	1704	1546	1167	733	824
35. R. G.	12.2	14.4	13.5	14.8	16.1	1333	974	1129	927	1223

APPENDIX B

FORMULAS

APPENDIX B

FORMULAS

1. $$V_{R_{BTPS}} = V_{O_2} \frac{(b - a)}{(i - b)} \times \frac{B - pH_2O}{B - 47} \times \frac{310}{273 + t} - DS \quad \text{(Rahn, 1949)}$$

V_{O_2} = volume of 0 in bag and hose to valve

b = N_2 in bag at equilibrium (in decimals)

a = N_2 in O_2 bag (impurity in decimal)

i = N_2 in alveolar sample prior to rebreathing (use constant of .80)

B = barometric pressure

t = temperature of gas in spirometer

pH_2O = partial pressure of H_2O at spirometer temperature

DS = dead space in mouth, trachea, and bronchi

2. $$D = \frac{M_{b_a}}{\frac{M_{b_a} - M_{b_w}}{D_w} - (VR + VGI)} \quad \text{(Buskirk, 1961)}$$

M_{b_a} = mass of body in air (gms)

M_{b_w} = mass of body in water (gms)

D_w = density of water (.996 for 30°C)

VR = residual volume BTPS

VGI = correction for gas in GI tract (100 cc)

3. $$F(\%) = \frac{4.95}{D} - 4.5 \times 100 \quad \text{(Siri, 1956)}$$

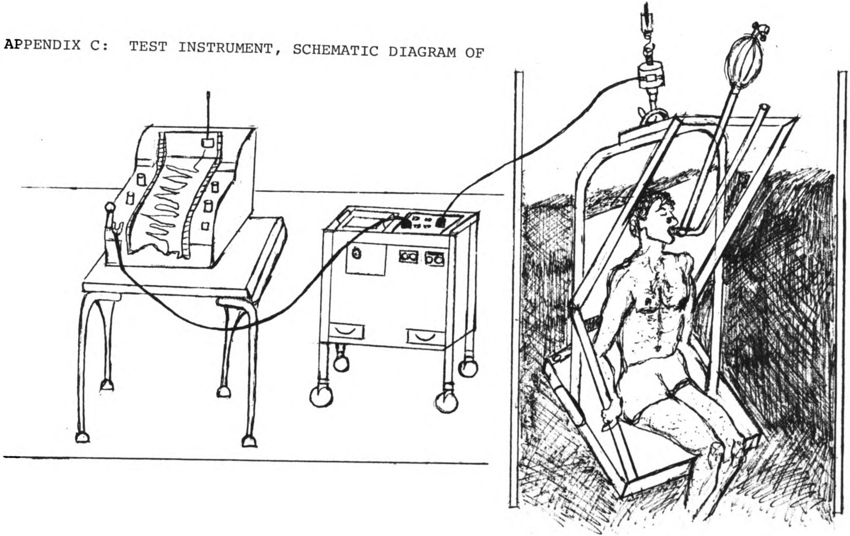
4. $$V_{R_{pred}} = (26 \times \text{age}) + (110 \times \text{height}) - 11 \times \text{weight}) - 4570$$

(Comroe, 1962)

APPENDIX C

TEST INSTRUMENT, SCHEMATIC DIAGRAM OF

APPENDIX C: TEST INSTRUMENT, SCHEMATIC DIAGRAM OF



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