THE VITAL CAPACITY IN A GROUP OF COLLEGE STUDENTS *

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The lessened vital capacity in intrathoracic diseases and the recommendation that vital capacity be used as a test of physical fitness have renewed interest in the question of normal standards for vital capacity. The vital capacity varies greatly even among healthy individuals, and some of the factors which accompany these variations are known. Among them are the sex, weight, height, size of the chest, age and general physical fitness. The clinician desires a normal standard with which he may compare the vital capacity of his patient. Would he do better, for example, to compare it with the average for individuals of the same height, of the same weight or of the same chest measurements; or should he use some combination of these? Obviously, that standard is best which shows the least variation among normal individuals. The convenience of the standard also deserves some consideration, for a convenient standard is more likely to be generally used.

Hutchinson [1] after examining about 3,000 men came to the conclusion that the most reliable standard for estimating the vital capacity of men was their standing height. He stated that on the average the vital capacity increased 8 cubic inches of air for every inch increase of height between the heights of 5 and 6 feet. According to Hutchinson the vital capacity increased also with the weight, but this occurred only up to an average weight of about 155 pounds. Increases of weight beyond this were not, on the average, accompanied by increased vital capacity. According to Hutchinson also the vital capacity tended to grow less after the age of about 33 years, although the chest circumference showed a slight tendency to grow greater. Peabody and Wentworth [2] grouped their normals into three classes according to height. This method has an obvious disadvantage in the case of those whose heights lie near the class borders, for they are compared with a standard that is best suited for a different height. Lundsgaard and Van Slyke [3] compared the vital capacity with certain chest dimensions;

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1. Hutchinson, J.: On the Capacity of the Lungs, and on the Respiratory Functions, with a View of Establishing a Precise and Easy Method of Detecting Disease by the Spirometer, Med. Chir. Tr. Lond. **29**:139, 1846.

2. Peabody, F. W., and Wentworth, J. A.: Clinical Studies on Respiration, Arch. Int. Med. **20**:443 (Oct.) 1917.

3. Lundsgaard, C., and Van Slyke, D. R.: Relation Between Thorax Size and Lung Volume, J. Exper. M. **27**:65, 1918.

but West [4] found a poor correlation between these dimensions and the vital capacity of his subjects. Dreyer [5] compared the vital capacity with the weight, the stem height (measured from the top of the head to the end of the sacrum) and the circumference of the chest. So far as weight was concerned, Dreyer neglected this in individuals whose weight did not correspond to their stem height; so that for practical purposes his comparisons were based on the stem height and the circumference of the chest. Finally West [4] compared the vital capacity with the surface area, as calculated from the height and weight by the DuBois' formula.[6]

Our observations were made on 400 normal young men at Leland Stanford Jr. University between the ages of 18 and 30. All of these were active and showed no evident signs of disease. In each case the height was taken in bare feet and the weight was stripped weight. The vital capacity was determined by a spirometer which gave accurate readings. Each individual was first shown how the test was performed and was then given three trials. The highest of the three readings was recorded as his vital capacity. The body surface area was estimated from the height and weight by using the diagram of DuBois and DuBois. Unfortunately, neither the sitting height nor the stem height according to Dreyer were taken. The individual observations are shown in Table 1.

A general conception of the relation between the vital capacities and weights of our students may be gained from Figure 1. The observations were grouped according to weights, and the average vital capacity for each weight group was determined. These averages increased with increasing weights but the rate of increase was relatively rapid at low weights and relatively slow at high weights. Hutchinson noted a similar change at the higher weights. In his statistics, however, the change at higher weights was more marked. We are inclined to attribute this difference to the fact that Hutchinson's observations included men of all ages. The excess fat so often accumulated as a person grows older is probably accompanied by no corresponding increase in vital capacity. Dreyer stated that the vital capacity is proportional to the 0.72 power of the weight ($W + ^{0.72}$). Dreyer's line representing this relationship is curved in the general direction of our averages; but the curve for the weights here under consideration is hardly appreciable. For the sake of comparison we have inserted

4. West, H. F.: Clinical Studies on Respiration; Comparison of Various Standards for Normal Vital Capacity of Lungs, Arch. Int. Med. **25**:306 (March) 1920.

5. Dreyer, G.: The Assessment of Physical Fitness, New York, Paul B. Hoeber, 1921.

6. DuBois, D., and DuBois, E. F.: Clinical Calorimetry. Fifth Paper. The Measurement of the Surface Area of Man, Arch. Int. Med. **15**:868 (June) 1915.

TABLE 1.—Vital Capacity of Group of College Students

Vital Capacity	Height	Weight	Surface Area	Vital Capacity	Height	Weight	Surface Area
6,700	187.0	80.4	2.06	5,277	181.1	93.2	2.14
6,555	186.7	75.7	1.98	5,244	173.3	63.6	1.77
6,555	193.7	87.7	2.17	5,200	180.0	67.2	1.86
6,655	189.2	82.3	2.07	5,200	175.5	61.5	1.76
6,500	195.5	85.6	2.18	5,200	175.3	65.0	1.78
6,200	180.5	79.0	1.99	5,200	174.5	64.4	1.78
5,981	185.4	77.3	1.98	5,161	187.0	77.3	2.01
5,981	184.0	94.1	2.14	5,114	178.0	71.4	1.88
5,899	172.0	70.5	1.83	5,163	182.8	78.2	2.01
5,860	187.2	65.0	1.87	5,163	171.6	69.5	1.81
5,899	185.4	75.0	1.95	5,163	171.0	67.3	1.76
5,817	172.7	70.9	1.82	5,150	170.5	64.4	1.75
5,800	179.5	71.6	1.90	5,100	174.0	61.6	1.75
5,760	185.0	77.0	2.03	5,081	175.9	64.5	1.80
5,736	180.0	60.5	1.77	5,081	182.9	72.7	1.92
5,736	180.0	76.4	1.95	5,081	176.0	66.4	1.78
5,736	180.3	90.0	2.10	5,081	184.0	86.4	2.08
5,736	184.0	78.2	2.00	5,074	174.0	72.7	1.88
5,736	181.2	68.2	1.95	5,065	172.0	65.0	1.77
5,752	191.0	79.5	2.08	5,031	183.0	70.0	1.90
5,736	180.3	72.7	1.90	5,081	182.5	70.5	1.90
5,736	187.9	65.0	1.88	5,073	172.0	78.1	1.92
5,700	174.5	72.4	1.87	5,081	174.0	79.5	1.94
5,700	186.0	70.2	1.93	5,081	187.0	69.1	1.94
5,637	184.0	76.8	1.96	5,081	180.6	82.3	2.01
5,654	185.0	68.7	1.92	5,081	176.0	78.6	1.95
5,572	185.4	79.5	2.03	5,081	183.0	84.1	2.06
5,572	185.4	82.3	2.05	5,077	180.0	70.9	1.89
5,572	188.1	78.2	2.06	5,031	179.0	81.0	1.98
5,572	191.0	94.0	2.24	5,000	179.5	65.2	1.83
5,572	190.5	92.2	2.20	5,000	175.0	78.5	1.94
5,572	185.3	78.2	2.03	5,000	173.0	64.3	1.78
5,572	182.8	75.0	1.96	5,000	183.0	75.2	1.97
5,571	173.0	71.4	1.83	5,000	170.8	64.1	1.75
5,505	184.0	63.6	1.85	4.916	175.5	70.5	1.85
5,500	179.0	64.6	1.82	4,998	167.6	65.0	1.74
5,450	177.7	70.6	1.88	4,916	180.3	67.3	1.84
5,490	179.1	63.6	1.83	4.916	172.0	67.0	1.77
5,490	185.4	84.0	2.07	4.916	184.0	64.5	1.85
5,407	170.0	77.3	1.87	4,916	173.0	63.6	1.77
5,407	186.5	85.0	2.10	4,916	170.0	71.8	1.82
5,407	187.2	72.7	1.95	4,916	180.0	65.9	1.84
5,407	188.0	71.4	1.96	4,916	172.5	70.0	1.83
5,410	178.1	79.5	1.98	4,949	185.6	66.8	1.87
5,420	189.0	83.2	2.07	4,916	172.5	69.0	1.83
5,415	180.3	77.5	1.95	4,916	185.6	74.1	1.97
5,488	177.8	62.3	1.76	4,982	184.0	72.7	1.96
5,407	177.0	60.0	1.75	4,952	190.0	78.1	2.06
5,405	177.5	58.2	1.76	4,900	185.0	73.2	1.94
5,325	185.3	84.1	2.08	4,916	173.2	79.5	1.93
5,325	181.8	84.1	2.03	4,916	183.6	71.4	1.92
5,320	178.0	60.5	1.76	4,916	182.8	84.1	2.06
5,325	185.3	70.0	1.93	4,998	177.8	63.0	1.81
5,325	175.2	65.9	1.79	4,916	181.5	71.0	1.89
5,338	181.0	70.5	1.89	4,900	177.8	66.7	1.83
5,300	180.0	64.1	1.83	4,916	178.3	70.0	1.87
5,340	170.0	70.3	1.81	4,916	177.8	60.5	1.75
5,325	180.3	68.0	1.87	4,998	180.3	61.0	1.77
5,300	181.0	80.8	2.01	4,916	179.0	74.0	1.93
5,300	168.0	63.3	1.72	4,998	179.0	67.8	1.87
5,300	181.5	70.4	1.90	4,916	174.8	79.5	1.95
5,300	181.8	74.4	1.95	4,916	168.5	66.9	1.76
5,244	185.4	72.7	1.94	4,960	168.8	65.0	1.73
5,244	175.9	64.5	1.79	4,900	169.0	66.0	1.77
5,244	179.0	63.0	1.83	4,900	169.0	72.0	1.83
5,244	173.9	68.6	1.84	4,900	172.5	68.2	1.81
5,244	173.0	64.0	1.76	4,850	179.0	63.6	1.80
5,211	184.0	70.0	1.91	4,850	175.8	67.8	1.83
5,235	174.0	94.0	2.08	4,850	175.0	60.5	1.74
5,244	175.5	80.0	1.95	4,800	171.0	65.0	1.77
5,244	177.0	69.1	1.86	4,800	178.0	65.2	1.82
5,260	178.1	71.8	1.88	4,834	175.4	68.2	1.84
5,244	180.6	80.0	2.00	4,850	186.5	82.7	2.07
5,244	185.6	72.7	1.96	4,834	184.0	92.0	2.14
5,244	185.0	66.9	1.91	4,834	175.2	70.0	1.85
5,244	188.0	77.7	2.06	4,741	172.7	67.3	1.78
5,244	174.0	77.7	1.94	4,734	175.9	75.9	1.91
5,244	167.6	58.2	1.68	4,752	172.0	63.6	1.76
5,277	184.0	70.5	1.92	4,752	184.0	69.1	1.91
5,252	176.0	72.3	1.86	4,752	173.0	71.8	1.84
5,244	180.8	76.3	1.95	4,752	180.3	70.5	1.89

TABLE 1.—Vital Capacity of Group of College Students—(*Continued*)

Vital Capacity	Height	Weight	Surface Area	Vital Capacity	Height	Weight	Surface Area
4,752	170.0	67.5	1.80	4,425	187.2	79.5	2.05
4,734	170.0	68.2	1.80	4,425	175.8	68.2	1.85
4,752	173.0	65.0	1.77	4,425	179.0	62.8	1.82
4,788	187.2	77.3	2.00	4,425	172.0	60.5	1.71
4,700	173.0	64.0	1.76	4,420	172.7	67.3	1.77
4,752	176.0	68.0	1.85	4,416	170.0	71.8	1.82
4,752	184.0	78.1	2.02	4,425	184.0	72.7	1.94
4,734	178.0	70.0	1.87	4,425	174.0	78.0	1.94
4,752	173.0	65.4	1.78	4,425	170.0	79.5	1.92
4,752	183.0	70.0	1.91	4,425	180.3	90.9	2.10
4,752	185.4	77.7	2.03	4,425	168.2	55.0	1.63
4,752	182.8	79.5	2.02	4,416	175.0	84.5	2.00
4,752	189.0	68.2	1.95	4,425	177.4	68.7	1.86
4,752	173.0	68.2	1.84	4,457	170.0	66.9	1.78
4,752	181.0	82.3	2.00	4,440	178.0	78.2	1.97
4,746	183.0	84.1	2.06	4,409	166.5	56.0	1.62
4,752	186.5	68.5	1.94	4,463	169.9	58.6	1.69
4,760	175.7	82.7	1.99	4,425	169.0	59.1	1.69
4,760	175.6	60.0	1.74	4,440	172.5	72.3	1.83
4,752	181.0	66.9	1.86	4,450	173.8	57.6	1.69
4,750	176.0	66.0	1.81	4,400	161.5	59.5	1.63
4,700	176.0	60.2	1.74	4,400	173.5	64.8	1.78
4,700	177.0	74.2	1.91	4,400	177.8	71.6	1.89
4,700	178.0	62.4	1.78	4,400	183.0	70.8	1.92
4,700	171.0	63.5	1.75	4,343	176.0	65.5	1.80
4,700	182.0	70.5	1.91	4,343	170.1	60.5	1.70
4,700	169.0	74.4	1.85	4,343	162.0	64.5	1.69
4,670	175.9	67.3	1.81	4,343	175.7	74.5	1.90
4,670	172.7	67.3	1.79	4,343	168.0	66.4	1.76
4,670	180.3	68.2	1.88	4,350	163.3	60.0	1.65
4,670	180.3	66.4	1.84	4,300	169.0	67.4	1.78
4,600	180.0	72.7	1.92	4,300	174.0	57.2	1.69
4,670	170.0	64.5	1.75	4,300	179.0	60.2	1.77
4,600	166.0	63.2	1.69	4,300	167.5	58.8	1.67
4,670	175.4	60.0	1.74	4,300	166.0	64.8	1.72
4,670	184.0	94.5	2.18	4,251	168.0	67.5	1.78
4,626	174.0	81.2	1.94	4,250	170.0	60.0	1.70
4,670	185.3	70.5	1.93	4,250	169.0	60.5	1.69
4,612	175.2	72.3	1.85	4,250	162.0	63.2	1.64
4,662	179.0	63.0	1.82	4,251	180.0	67.8	1.87
4,670	175.2	65.9	1.79	4,251	170.1	63.6	1.75
4,650	170.4	63.6	1.74	4,251	176.4	87.7	2.06
4,600	174.0	68.0	1.82	4,211	176.0	69.1	1.85
4,600	173.5	65.2	1.79	4,250	172.6	88.8	2.03
4,600	173.5	88.9	1.84	4,250	165.0	65.0	1.73
4,588	175.9	60.5	1.75	4,211	173.0	75.0	1.88
4,588	182.9	60.5	1.79	4,251	177.0	60.0	1.75
4,588	170.2	60.5	1.70	4,251	167.6	56.0	1.63
4,588	170.0	67.5	1.78	4,250	178.0	68.7	1.87
4,588	177.2	114.5	2.29	4,242	170.0	61.8	1.72
4,506	180.0	67.3	1.85	4,245	174.0	60.5	1.73
4,588	176.0	68.6	1.86	4,250	173.6	64.5	1.77
4,506	178.0	72.7	1.93	4,250	166.5	57.7	1.66
4,588	182.5	72.7	1.92	4,250	178.0	68.2	1.87
4,580	176.0	68.2	1.86	4,250	164.0	64.5	1.72
4,572	171.0	64.5	1.76	4,250	172.5	62.2	1.74
4,580	182.0	66.0	1.84	4,210	180.2	55.5	1.71
4,588	180.5	76.8	1.95	4,200	175.6	65.8	1.81
4,572	183.1	69.1	1.90	4,200	167.5	51.4	1.57
4,506	173.8	66.4	1.78	4,200	172.0	57.3	1.68
4,580	189.0	78.2	2.06	4,200	165.0	56.3	1.62
4,506	183.0	78.0	2.01	4,200	171.0	57.4	1.67
4,597	172.1	70.0	1.82	4,100	186.0	60.0	1.82
4,500	187.0	67.3	1.92	4,179	160.0	64.5	1.68
4,506	176.0	80.4	1.96	4,170	172.6	81.2	1.94
4,500	174.0	86.8	2.02	4,170	177.8	67.3	1.85
4,506	173.8	68.2	1.84	4,180	173.5	62.7	1.77
4,588	180.3	74.0	1.94	4,180	181.5	70.5	1.89
4,588	181.5	70.5	1.89	4,180	170.0	64.5	1.75
4,580	180.3	77.2	1.96	4,100	171.5	57.0	1.67
4,506	178.0	72.3	1.88	4,100	174.0	64.0	1.78
4,539	180.0	68.2	1.88	4,087	172.7	54.4	1.65
4,506	163.0	69.5	1.75	4,087	179.1	60.4	1.77
4,506	175.2	70.9	1.85	4,080	168.9	54.5	1.63
4,588	180.3	65.9	1.83	4,087	180.3	61.8	1.78
4,588	173.5	71.4	1.84	4,087	172.0	60.5	1.72
4,520	174.0	57.0	1.69	4,080	176.0	67.3	1.83
4,500	167.0	62.5	1.70	4,087	176.0	62.7	1.77
4,500	187.5	57.6	1.79	4,087	183.0	75.6	1.97
4,500	170.0	53.5	1.62	4,070	162.0	60.0	1.64
4,500	164.3	62.2	1.68	4,087	172.6	57.3	1.68

TABLE 1.—Vital Capacity of Group of College Students—(*Continued*)

Vital Capacity	Height	Weight	Surface Area	Vital Capacity	Height	Weight	Surface Area
4,087	171.3	53.2	1.60	3,750	160.0	70.5	1.73
4.095	176.4	62.3	1.75	3,769	162.5	57.5	1.59
4,015	173.4	71.4	1.84	3,730	163.0	84.5	1.90
4,050	170.1	80.4	1.92	3,769	165.0	57.7	1.66
4,015	170.0	55.4	1.64	3,750	175.5	58.8	1.72
4,015	165.0	54.6	1.60	3,750	168.5	56.5	1.64
4,087	168.2	63.6	1.73	3,605	172.6	59.1	1.70
4,087	164.0	64.5	1.71	3,605	157.4	47.3	1.46
4,050	166.3	59.8	1.67	3,687	172.6	68.2	1.82
4,050	172.0	57.3	1.68	3,687	162.5	60.0	1.64
4,050	172.2	60.9	1.72	3,605	177.8	57.0	1.74
4 050	172.5	55.9	1.67	3,687	185.0	58.4	1.79
4,000	169.5	60.0	1.69	3,687	173.0	59.1	1.72
4,000	173.6	58.7	1.70	3,605	172.0	60.0	1.72
3,960	172.7	60.5	1.72	3,688	167.6	65.9	1.75
3,982	168.3	60.4	1.68	3,675	171.0	66.9	1.77
3,960	176.0	63.6	1.80	3,625	170.0	55.9	1.64
3,933	180.0	77.3	1.96	3,687	179.0	62.2	1.77
3,933	173.0	58.2	1.70	3,687	175.2	53.9	1.66
3,900	180.3	74.5	1.94	3,605	171.0	66.9	1.78
3,933	158.7	60.0	1.63	3,650	160.7	57.3	1.60
3,960	169.0	62.7	1.73	3,600	157.5	62.0	1.63
3,933	168.0	75.9	1.86	3,500	162.8	56.0	1.60
3,933	170.5	59.1	1.70	3,400	166.9	58.0	1.65
3,950	169.0	58.8	1.68	3,441	180.3	68.2	1.78
3,910	174.5	72.0	1.87	3,441	166.0	65.4	1.74
3,900	160.6	53.4	1.55	3,450	167.0	65.0	1.74
3,900	167.0	62.5	1.70	3,425	187.0	59.1	1.83
3,851	182.8	67.8	1.90	3,441	170.1	60.0	1.70
3,842	172.6	65.3	1.77	3,472	170.1	75.9	1.82
3,851	167.6	56.8	1.64	3,359	169.5	58.2	1.69
3,801	176.6	64.5	1.79	3,277	176.0	61.0	1.75
3,802	179.0	63.2	1.81	3,290	168.0	52.3	1.57
3,769	172.0	67.5	1.78	3,277	160.8	63.6	1.65
3,769	179.0	60.4	1.76	3,277	164.3	52.7	1.55
3,769	168.9	70.7	1.81	3,150	167.0	66.9	1.77
3,769	170.0	58.2	1.68	3,115	165.0	63.6	1.69
3,769	179.3	58.6	1.76	3,048	175.5	60.0	1.74

in Figure 1 the straight line relationship between weight and vital capacity as calculated from our data, Dreyer's line, and Hutchinson's averages of vital capacity for different weight groups. The lower averages in Hutchinson's statistics will be considered farther on.

Figure 2 indicates for our students the average vital capacities of the different height groups. We have added the similar averages of Hutchinson's cases, the straight line relationship between vital capacity and height as calculated from our data and the straight line relationship which Hutchinson proposed for his. Both in our cases and in those of Hutchinson the relationship between the height and the vital capacity for height groups approached a straight line.

The statistical methods employed are based on two assumptions. The first is that the relationship between the factors compared approaches a straight line relationship. We have shown that this is approximately the case so far as the relation between height and vital capacity is concerned. The relation between weight and vital capacity deviates somewhat from a straight line in the case of our students and this deviation is quite marked in Hutchinson's observations. The second assumption is that the data for each group of observations approximates the so-called normal distribution curve. This is true of

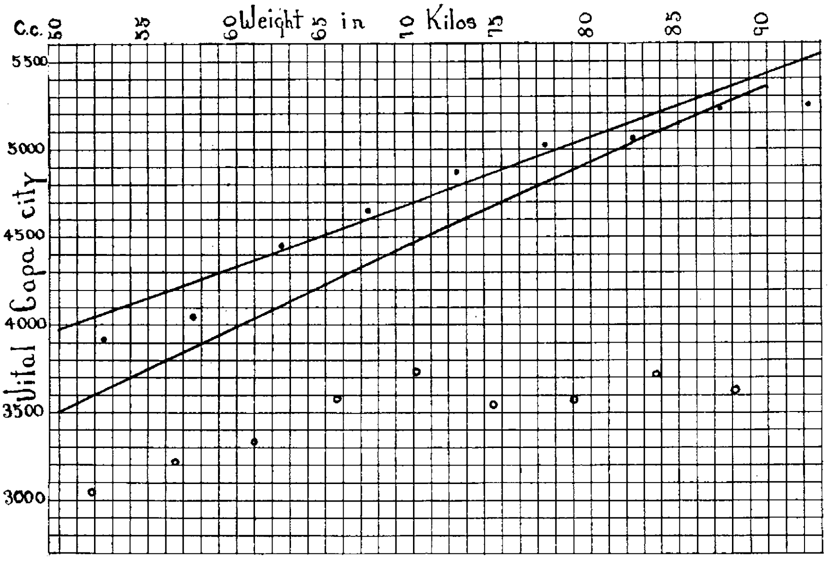

Fig. 1.—The vital capacity and weight. The dots represent the average vital capacities for different weight groups of Stanford students. The circles represent similar averages for Hutchinson's cases. The upper straight line is the calculated line for Stanford students. The line just below is Dreyer's line. Its curve is hardly perceptible.

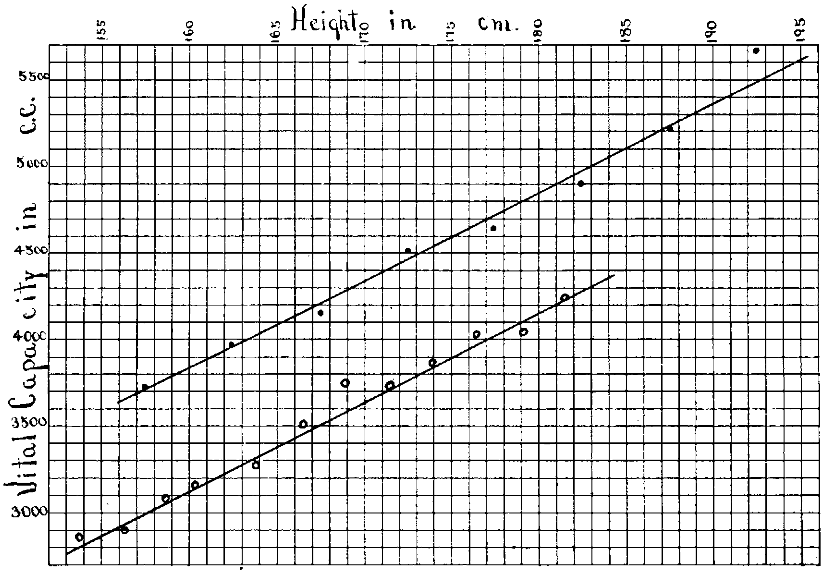

Fig. 2.—The vital capacity and height. The dots represent the average vital capacities for different height groups of Stanford students. The circles represent similar averages for Hutchinson's cases. The upper straight line is the calculated line for Stanford students. The lower straight line is that proposed by Hutchinson.

biologic measurements in general, including height and weight. It is also true of the vital capacity. Figure 3 shows the actual observations in Stanford students and the calculated theoretical distribution curve.

With the above assumption it is possible by the mathematical methods employed in statistical studies to determine the relation of vital capacity to height, to weight and to their combination. For determining these relations in college students we have used our figures on 400 Stanford students, the figures of West on eighty-five Harvard medical students and the figures of Schuster [7] on 959 Oxford students. For comparison, Hutchinson's data on 1,285 men as shown in his Table D have also been used. We have calculated from these data the standard deviations, the coefficients of correlation, and the formulas which best express the straight line relationship between vital capacity

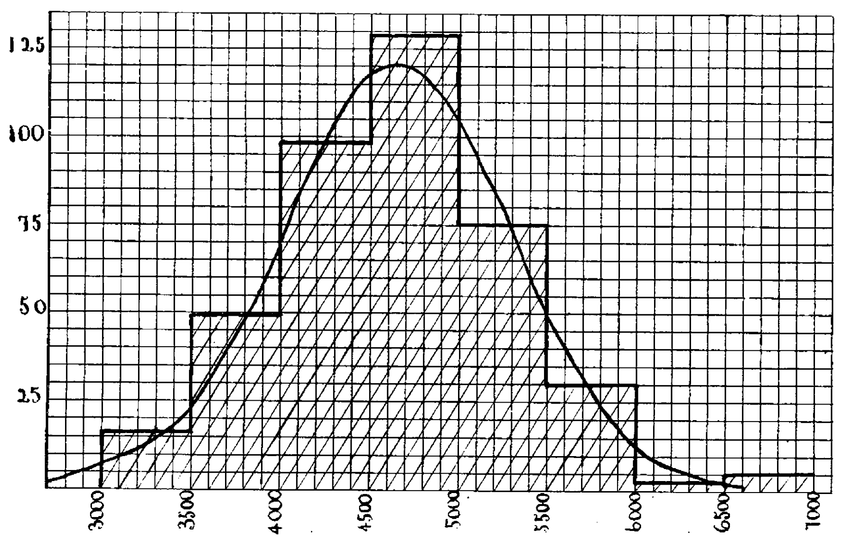

Fig. 3.—The frequency curve for the vital capacities of Stanford students. The shaded columns represent the number of observations between different limits of vital capacity. The curve represents the theoretical distribution as calculated from the standard deviation, the mean, and the total number of observations.

and various other factors. The methods used are described in Yule's "Introduction to the Theory of Statistics."

Briefly, it may be stated that the standard deviation expresses the dispersion of the data on either side of the average. It is expressed by the formula $\sigma = \sqrt{\frac{\Sigma x^2}{N}}$ where σ is the standard deviation, x is the deviation of any one point from the average, Σx^2 is the sum of the squares of these individual deviations, and N is the number of observations.

7. Schuster, E.: First Results from the Oxford Anthropometric Laboratory, Biometrika **8**:40, 1911.

The coefficient of correlation, r, indicates how closely the observations of any two sets of data on the same individuals, e. g. vital capacity and height, range themselves about a straight line relationship. It is calculated from the formula $r = \frac{\Sigma xy}{N \sigma x \sigma y}$ where x and y represent the deviations of each point from the averages of x and y, respectively, Σxy the sum of the products of these deviations, N the number of observations and σx and σy the standard deviations of the two groups of observations that are being compared, e. g., vital capacity and height. The more nearly r approaches unity the more closely do the data range themselves on a straight line, i. e., the more exact is the linear correlation. A mathematical expression for the line of relationship is given by the formula $y = a + r \frac{\sigma y}{\sigma x} x$ where for example, y represents the vital capacity, x the height, r the coefficient of correlation between height and vital capacity, σy the standard deviation of the vital capacity, σx the standard deviation of the height and a is a constant. The standard deviation of the individual observations from this calculated line is represented by the expression $\sigma y \sqrt{1 - r^2}$.

TABLE 2.—Results of Comparison of Data from Three Groups of Students

	Oxford	Harvard	Stanford	S. & H.	S. H. & O.	Hutchinson
Number	959	85	400	485	1,444	1,285
Means:						
Weight	68.52	64.50	68.49	....	68.28	68.30
Height	176.5	173.6	175.9	....	176.2	171.5
Vital capacity	4,315	4,651	4,646	4,647	4,426	3,602
Surface area	....	1.776	1.835	1.825		
Standard Deviations:						
Weight	7.428	7.176	8.831	....	7.885	8.796
Height	6.608	6.856	7.121	....	6.805	6.637
Vital capacity	613.2	652.5	655.8	655.3	646.9	(446.3)*
Surface area	....	0.1167	0.1332	0.1324	....	....
Coefficients of Correlation:						
Wt. : Ht.	0.66	0.61	0.50	....	0.60	0.60
Wt. : V. C.	0.59	0.67	0.49	....	0.53	(0.63)*
Ht. : V. C.	0.57	0.63	0.55	....	0.53	(0.86)*
S. A. : V. C.	....	0.73	0.57	0.59		

* Calculated from Hutchinson's averages as given in his Table D. The use of averages makes the standard deviation too small and the coefficients of correlation too large.

Table 2 gives the results obtained by these statistical calculations. In the group studied by Hutchinson, which comprised men of different ages and different occupations, the average weight was the same as the average weight of the college students, whereas the average height was definitely less. On the average, then, Hutchinson's subjects were somewhat shorter and relatively fatter than our students. The average vital capacity differed considerably in the different groups. The Stanford and Harvard medical students showed the highest average vital capacity; the Oxford average was about 7 per cent. lower and Hutchinson's average group was more than 20 per cent. lower. This low average in Hutchinson's group was probably due, in part, to the fact that he studied men of all classes and all ages, whereas college students represent a picked class both as to age and general physical fitness. It seems unlikely, however, that the low average in Hutchinson's group was due entirely to this cause. Difference in technic or in the instruments used may have been partly responsible for his low figures.

Fluctuations on either side of the average are indicated by the standard deviations given in Table 2. These fluctuations were greater among the Stanford students than among the Oxford or the Harvard medical students. In all groups the fluctuations of vital capacity were relatively greater than the fluctuations of either weight or height. Thus for all students the standard deviation for vital capacity amounted to 14.6 per cent. of the mean, the standard deviation for weight amounted to 11.5 per cent. of the mean, and the standard deviation for height amounted to 3.9 per cent. of the mean. It is evident, therefore, both from the different averages and from the standard deviations that the vital capacity of normal individuals shows a rather wide range of fluctuation.

Table 2 shows also that among college students the correlation between weight and vital capacity is approximately the same as the correlation between height and vital capacity. Hutchinson did not record the individual vital capacities of his subjects and it is not possible from his data properly to calculate correlation coefficients for vital capacity and either weight or height. We have, however, made such calculations from the average vital capacities given in his Table D. From these it is evident, as he stated and as is shown in our Figures 1 and 2, that for his cases the correlation of vital capacity with height is far better than the correlation with weight. This difference between college men and men at large with respect to the correlation of weight and vital capacity may be explained on the assumption that the latter group includes some fat men whose excess weight is accompanied by no increase or perhaps by a decrease of vital capacity. It seems to us, therefore, that weight is not a reliable index of vital capacity unless one can exclude those with excess fat.

Among college students, where excess fat is not common, there is a closer correlation between vital capacity and a combination of weight and height than between vital capacity and either height or weight alone. West proposed that the body surface as calculated from the weight and height be used as an index of vital capacity and it may be seen from Table 2 that the correlation with body surface is somewhat better than the correlation with either height or the weight alone. A combination of the linear relationships of vital capacity to weight and to height was calculated. This correlation will be discussed later.

By applying the methods of statistical study to the above data, formulas may be obtained by means of which one may calculate for college students the probable vital capacity either from the height, from the surface area, or from the linear combination of height and weight. The first and last formulas are based on the combined Stanford, Oxford and Harvard medical statistics. The second is based on the correlation coefficient between vital capacity and surface area of the Stanford and the Harvard medical groups and on the average for all students. The formulas obtained are as follows:

$$VC=50\ Ht-4{,}400$$

$$VC=2{,}900\ SA-1{,}000$$

$$VC=27\ Wt+31.5\ Ht-3{,}000$$

In these formulas vital capacity is expressed in cubic centimeters, height in centimeters, surface area in square meters and weight in kilograms.

The standard deviations of the observed vital capacities of students from vital capacities which have been calculated from the above formulas are as follows:

Standard deviation of vital capacities from height formula, 548.6 c.c.

Standard deviation of vital capacities from surface area formula, 529.1 c.c.

Standard deviations of vital capacities from weight and height formula, 521.1 c.c.

TABLE 3.—Showing Number of Students Out of Each Hundred Who May Be Expected to Have a Vital Capacity Which Falls Below the Following Percentages of Their Calculated Vital Capacity, When the Different Formulas Are Used

	Falling Below				
	90%	85%	80%	75%	70%
Height formula	21.0	11.3	5.4	2.2	0.8
Surface formula	20.1	10.5	4.8	1.8	0.6
Height-Weight formula	19.8	10.2	4.5	1.7	0.6

It will be seen that in the case of college students the fluctuations from a formula based on both height and weight are less than the fluctuations from a formula based on height alone. Between the formula based on the calculated body surface area, and the formula based on linear relationships between vital capacity and height and weight, there is no significant difference. This conclusion, of course, applies only to college students. The significance of these standard deviations can better be appreciated if one compares how many out of each hundred college students will have a vital capacity that falls below any assumed percentage of the calculated vital capacity. Table 3 gives these figures.

Of every hundred college students approximately twenty-one will have a vital capacity less than 90 per cent. of that calculated by the height formula, and approximately twenty will have a vital capacity less than 90 per cent. of that calculated by the body surface or by the height-weight formula. On the other hand, only about two will have a vital capacity less than 75 per cent. of the calculated amount. We have compared the calculated fluctuations among Stanford students with those actually observed and find a close agreement between the two.

DISCUSSION

College students constitute an excellent group for determining normal vital capacity standards. They are young, intelligent and healthy. In this test intelligence is a factor because the test demands a maximum effort and statistics might easily be impaired if some subjects did not understand the instructions or did not make the necessary effort.

By applying statistical methods of study to the figures obtained from college students we have determined which gave the best index of vital capacity—the height, the weight or a combination of these; we have obtained formulas by which one may predict the average vital capacity for students from their heights or a combination of these with their weights; and we have defined the probable fluctuations from these calculated averages. Unfortunately, we have not the figures necessary for comparing the vital capacity with the sitting or with Dreyer's stem height, but we hope later to report on the value of this standard as judged by college statistics.

Most standards for vital capacity are based on the assumption that there is a simple ratio between the vital capacity and some body measurement or some power of this measurement. Thus the ratio to the height, to the surface area or to some power of the weight or stem length is given. Statistical formulas usually introduce an additional constant which is added to or subtracted from one side of the equation. This distinguishes our formulas from those that have been proposed.

Our formulas are strictly applicable only to college students. How far may they applied to a larger field? We have no figures which answer this question but it is evident from the work of others that they are quite inapplicable to females in general,[4] as well as boys.[8] Furthermore, our standard is a high one for men at large, partly because college students represent a picked class and, partly, because the vital capacity tends to lessen as persons grow older. Excess fat is a disturbing factor in any formula which is based on weight. For this reason we have given no weight formula and we suspect that for men in general a formula based on height and weight combined may be no better than one based on height alone.

Vital capacity varies considerably even in such a selected group as college students and even when it is compared with the height or with a combination of height and weight. The amount of these

8. Emerson, P. W., and Gue, H.: Vital Capacity of the Lungs of Children, Am. J. Dis. Child. **22**:202 (Aug.) 1921.

variations is shown in Table 3. What constitutes an abnormal reduction of the vital capacity? The answer to this question depends on whether we are comparing individuals or group averages with the standard. The difference between different groups of normal individuals is illustrated by the deviations of the Oxford average and the Harvard medical average from our standard for college students. Making allowances for height, the former is 2.5 per cent. below the average and the latter 8.7 per cent. above the average. To be significant, a group average should probably differ from the college standard by not less than 10 per cent. With respect to individual observations, our study shows that of every hundred college students about two have a vital capacity that is less than 75 per cent. of the standard. Assuming that an occasional student has some unrecognized disease, we may conclude that for men in general a reduction below 70 per cent. of the standard is almost always abnormal. Studies on heart patients and on patients with pulmonary tuberculosis indicate that in these diseases the vital capacity frequently falls below this figure.

CONCLUSIONS

1. Among college students the correlation of vital capacity with height and the correlation of vital capacity with weight are approximately equal. The correlation of vital capacity with a combination of weight and height is a little better than the correlation with either separately.

2. Formulas are given which express the average vital capacity of college students for different heights and combinations of height and weight.

3. From these formulas there is a very considerable fluctuation even among college students. The fluctuations for men in general, and the deviations in disease must necessarily be still greater.