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# Human Body Buoyancy: A Study of 98 Men

Can any conclusions regarding cause of death be drawn from whether a body floats or sinks in water? In 1699 a famous British murder trial was precipitated by the discovery of a young woman's body floating on the surface of a millpond very soon after death. The townspeople could not reconcile this circumstance with anything but foul play, and four lawyers were charged with her murder. Among the evidence presented was the testimony of a sailor who recounted that at the naval battle of Beachy Head the men who were shot and fell overboard floated, while those who were drowned immediately sank [*1*].

Miles [*2*] stated, "Most men, in fresh water, will if they take a full breath, remain on the surface with just a little of the scalp above water, i.e., be positively buoyant. About 10%—the so-called 'negatively buoyant' will actually sink." Simpson [*3*] said, "As a general rule the recently *dead* unclothed body is *heavier* than water and sinks when immersed." Adelson [*4*] stated, "Because the specific gravity of the lifeless human body, regardless of the cause of death, exceeds the specific gravity of fresh or sea water, any recently dead person always sinks to the ocean floor, river bed, lake, or pool bottom." Spitz [*5*] said, "A body in water will sink unless air trapped among the clothes keeps it afloat." Snyder [*6*,p. 218] stated, "The human body is slightly heavier than fresh water.... Fat bodies are slightly more buoyant than are thin bodies, but still all bodies will sink in fresh water." He noted, however, that, "Occasionally it is true that a body will drown in fresh water yet not sink" under unusual circumstances [*6*,p. 222].

Archimedes' principle states that an object in water will experience a buoyant force equal to the weight of the water it displaces. An object will sink if the weight of water it displaces is less than its own weight. If an object displaces a weight of water greater than its weight, it will rise to the surface and float. A floating object in equilibrium at the surface displaces its own weight of water.

Specific gravity is a useful concept for predicting whether a body will float or sink. The specific gravity of the human body relates the weight and volume of the body to the weight and volume of the reference standard water. A body with a specific gravity of greater than 1.000 will sink in freshwater, while one with a specific gravity of 1.000 or less will float in freshwater.

Human specific gravity is affected by height, weight, and composition of the body

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tissue. It can be altered by devices attached to the body such as clothes, life preservers, or weighting devices. Increases in volume without significant weight changes (for example, inspiration of air or formation of bacterial gas) tend to decrease specific gravity. Increases in weight without significant volume changes (for example, attaching heavy weights or filling the stomach or lungs with water) tend to increase the specific gravity. The latter would be analogous to flooding the compartments of a ship.

Gases contained in expandable body cavities, especially the chest and abdomen, contribute to the specific gravity. Thus, the specific gravity of the human body varies with each inspiratory-expiratory breathing cycle. This is reflected in the experience of scuba divers, who find that they bob up and down with each respiration while attempting to work at a fixed depth.

Snyder [*6*, p. 218] noted, and we concur, that once a body begins to sink it goes directly to the bottom. The reason is hydrostatic pressure, which increases with depth—1 atm (0.1 MPa) for every 33 ft (10 m) in freshwater. As a body sinks, gas contained in the chest and abdomen is compressed. This increases body specific gravity, decreases bouyancy, and accelerates sinking.

The effects of changes in lung volume on the specific gravity of a human body are considerable, and any method of measuring specific gravity that fails to consider this is likely to be incomplete and misleading. In 1942 Behnke et al [*7*] measured the specific gravities of 99 healthy U.S. Navy men in the 20 to 40-year age group and corrected these values for the amount of air contained in the lungs at residual volume. This yielded a specific gravity value for the theoretical situation in which the lungs were completely empty and allowed comparison of specific gravity values without regard to the volume of air contained in the lungs. The specific gravities in the study, corrected for residual volume, ranged from 1.021 to 1.097.

In publishing the results of their study, averages of group data were selected as the method of presentation. While their information was interesting and useful, it did not allow examination and manipulation of individual data. One of the authors, Captain A. R. Behnke, MC, USN (Ret.), was kind enough to furnish all available data for this study. From this information the specific gravities and buoyancies at various lung volumes were calculated for 98 subjects.[3]

## Methods and Materials

In the 1942 study by Behnke et al [*7*] the weight of each subject in air was determined. The subjects were then suspended below the surface of the water and weighed twice: once at the completion of maximum inspiration and once at the end of maximum expiration. The difference in the weights obtained reflects hydrostatic displacement and serves to measure vital capacity, the maximum volume that can be voluntarily expelled from the lungs following a maximal inspiration. Residual volume, the amount of air remaining in the lungs after maximal voluntary expiration, was determined by the helium-dilution method.

In the present study the data were then used to calculate the specific gravity, buoyancy in freshwater, and buoyancy in seawater, at specified lung volume for each subject. In the metric system, specific gravity can be numerically equated with density for most practical purposes. Specific gravity $S$, then, can be expressed as the ratio of weight $W$ to volume $V$.

$$S \cong W/V \tag{1}$$

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[3] Data on lung volume were unavailable for one subject.

If the lungs are empty, $V = V_0$, then

$$S_0 = W/V_0 \tag{2}$$

where $S_0$ is the subject's specific gravity with lungs empty, $W$ is the subject's weight, and $V_0$ is the subject's volume with the lungs empty. The specific gravity at a given lung volume is defined by the expression

$$S_L = W/(V_0 + V_L) \tag{3}$$

where $S_L$ is the specific gravity at a given lung volume and $V_L$ is the given lung volume.

The designated lung volumes in the study were residual volume, functional residual capacity, and total lung capacity. To make this information of use to forensic scientists we must have some idea about how much air would be present in the lungs of a dead body. A 1970 U.S. Coast Guard study reported that a person entering the water in an unconscious state would have a lung volume near functional residual capacity plus variations caused by tidal volume [*8*]. For a recently dead body, a volume near functional residual capacity seems a reasonable approximation. Functional residual capacity, the volume of gas remaining in the chest at the end of a normal expiration, was calculated as 50% of the total lung capacity [*9*].

The buoyant force of water on a body at a given lung volume is expressed by

$$B = (V_0 D_w) + (V_L D_w) - W \tag{4}$$

where $B$ is the subject's buoyancy and $D_w$ is the density of water.

## Results

The results of the calculations are presented graphically in the figures. Figure 1 shows a cumulative frequency distribution of specific gravity values in the population studied. The lines at points 1.000 and 1.026 represent the specific gravity of freshwater and seawater, respectively. By looking at the freshwater line (1.000), it can be seen that none of the subjects had a specific gravity of 1.000 or less at residual volume; that is, all subjects would sink in freshwater with lungs at residual volume. At total lung capacity 100% of the subjects had a specific gravity of 1.000 or less, and all would float in freshwater. At functional residual capacity, the value approximating the lung volume of an unconscious or dead body, 7% of the subjects had a specific gravity of 1.000 or less and would float in freshwater.

Examination of the seawater line (1.026) shows that 100% of the subjects had a specific gravity of 1.026 or less at total lung capacity and would float in seawater. At residual volume, 9% had a specific gravity of 1.026 or less and would float in seawater. At functional residual capacity, 69% of the subjects had a specific gravity of 1.026 or less and would float in seawater.

By drawing lines at other specific gravity values it would be possible to determine what percentage of this population would float or sink in other liquids at the specified lung volumes.

Figures 2 and 3 show the cumulative frequency distribution of body buoyancy at specified lung volumes in the population studied. Figure 2 is for freshwater, Fig. 3 for seawater. Zero on the buoyancy axis represents neutral buoyancy. Values above zero indicate positive buoyancy: a body would float under these conditions. Values below zero indicate negative buoyancy: a body would sink under these conditions. The data in

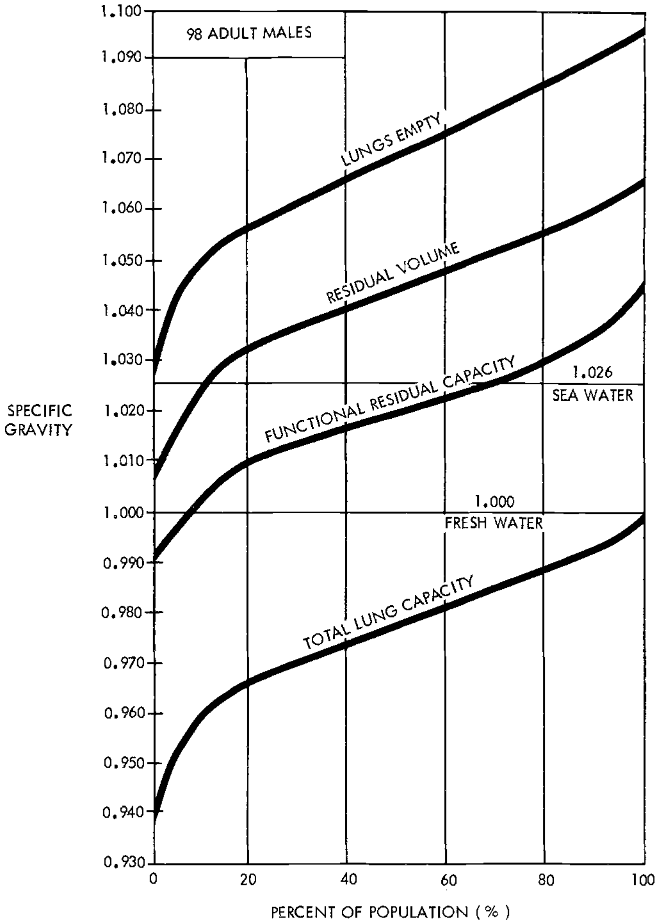

FIG. 1—*Percentage of population having a specific gravity equal to or less than the indicated value at specified lung volumes.*

Figs. 2 and 3 show how much added weight would be necessary to sink a percentage of the population, or how much added buoyancy would be needed to float a percentage of the population.

In freshwater, 11 lb (5 kg) of added weight would sink 100% of the population regardless of lung volume. Added buoyancy of 8 lb (3.6 kg) would allow 100% of the population to float at functional residual capacity. With this amount of added buoyancy some of the subjects would float with only the top of their heads breaking the surface, and more buoyancy would be needed to allow them to float with their heads and necks above the surface. To insure that a body floats with at least its head out of the water, a U.S. Coast Guard study recommended 26 lb (11.8 kg) of added buoyancy for personnel flotation devices [*8*,p. 46]. The 7% of the population capable of floating at functional residual capacity could be sunk with no more than 2 lb (0.9 kg) of added weight.

In seawater, 15 lb (6.8 kg) of added weight would sink 100% of the population regardless of lung volume. Added buoyancy of 4 lb (1.8 kg) would be required to float 100% of the population at functional residual capacity. It can be seen that seawater eases buoyancy requirements. Of the 69% of the population capable of floating at functional residual capacity, more than half could be sunk by 2 lb (0.9 kg) of added weight.

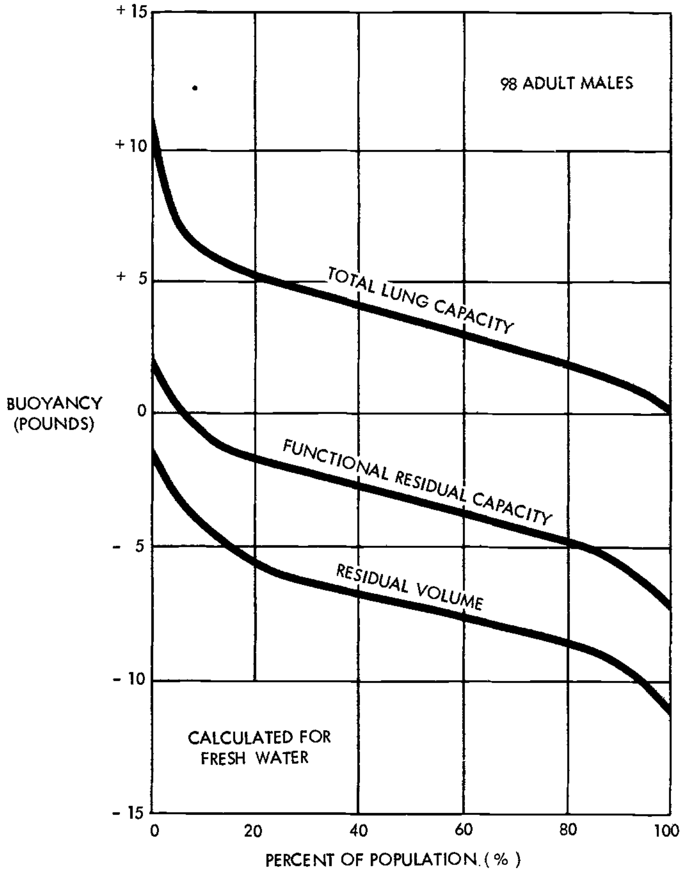

FIG. 2—*Percentage of population having a buoyancy in freshwater equal to or greater than the indicated value at specified lung volumes.*

## Discussion

Because the specific gravity of the human body is very close to that of water, small variations in specific gravity have considerable effect on buoyancy. All subjects in this study would be capable of floating in seawater or freshwater with their lungs inflated to total lung capacity. At functional residual capacity, the approximate lung volume of a dead body, some subjects would float and some would sink.

The small quantities of added weight required to sink the subjects capable of floating at functional residual capacity give some measure of the precarious equilibrium established by a fresh body found floating on the surface of the water. Because of the increase of hydrostatic pressure with increasing depth, once a body starts to sink, it will continue to sink to the bottom. Rough waters, helicopter downdrafts, or turbulence created by passing vessels could easily force floating bodies under the surface and sink them. No technique of recovery should push a body beneath the surface until the body is adequately secured.

The amount of water inhaled during drowning is unknown. Modell and Davis [*10*] estimated that 85% of both freshwater and seawater drowning victims aspirate 10 ml of fluid or less per pound of body weight (2.2 ml/kg). For a man weighing 170 lb (77 kg),

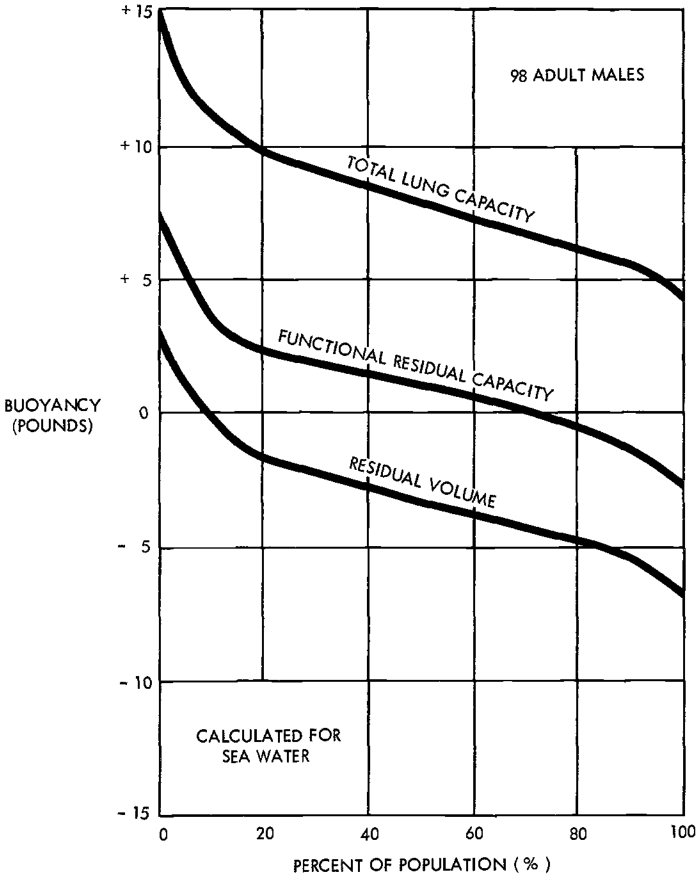

FIG. 3—*Percentage of population having a buoyancy in seawater equal to or greater than the indicated value at specified lung volumes.*

this would represent 1700 ml of aspirated water or 3.7 lb (1.7 kg) of added weight. Since any amount of aspirated water is added weight and since those bodies capable of floating at functional residual capacity are very near the neutral buoyancy point, drowned bodies, as a group, will be more likely to sink than bodies dead of other causes. In individual cases, however, no conclusion regarding cause of death can be drawn from whether a body floats or sinks.

## Summary

The specific gravity and buoyancy of 98 men were calculated at various lung volumes. The data indicated that all subjects would be capable of floating in either freshwater or seawater at total lung capacity. At functional residual capacity, the value approximating the lung volume of a recently dead body, 69% of the subjects would float in seawater, whereas only 7% would float in freshwater. Results of this study indicate that while drowned bodies are more likely to sink than bodies dead of other causes, no conclusion regarding the cause of death can be made on the basis of whether bodies float or sink.

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## References

[*1*] Lord Birkenhead, *Famous Trials,* Hutchinson and Co., London, 1926, pp. 89–99.
[*2*] Miles, S., *Underwater Medicine,* 3rd ed., J. B. Lippincott Co., Philadelphia, 1969, p. 37.
[*3*] Simpson, K., *Taylor's Principles and Practice of Medical Jurisprudence,* Vol. 1, 12th ed., Churchill Livingstone, London, 1965, p. 379.
[*4*] Adelson, L., *The Pathology of Homicide,* Charles C Thomas, Springfield, Ill., 1974, p. 563.
[*5*] Spitz, W. U. and Fisher, R. S., *Medicolegal Investigation of Death,* Charles C Thomas, Springfield, Ill., 1973, p. 304.
[*6*] Snyder, L., *Homicide Investigation,* 2nd ed., Charles C Thomas, Springfield, Ill., 1972.
[*7*] Behnke, A. R., Feen, B. A., and Welham, W. C., "The Specific Gravity of Healthy Men," *Journal of the American Medical Association,* Vol. 118, No. 7, 1942, pp. 495–498.
[*8*] "Final Report on Buoyancy and Stability Characteristics of the Human Body and Personnel Flotation Devices," prepared by Arthur D. Little, Inc., consultants, for U.S. Coast Guard, Washington, D.C., 1970.
[*9*] Fenn, W. O. and Rahn, H., *Handbook of Physiology,* Sec. 3, Vol. II, American Physiological Society, Washington, D.C., 1965, p. 1359.
[*10*] Modell, J. H. and Davis, J. H., "Electrolyte Changes in Human Drowning Victims," *Anesthesiology,* Vol. 30, No. 4, 1969, pp. 414–420.

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