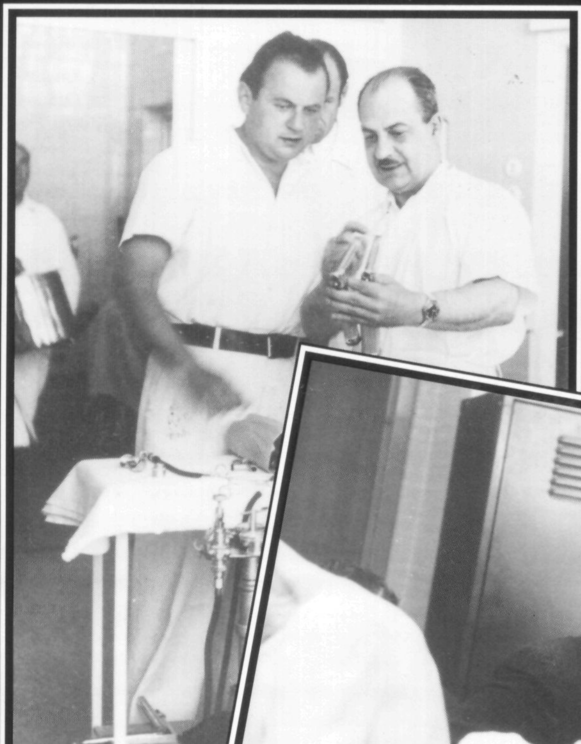
The History of Anesthesiology

Reprint Series: Volume 24

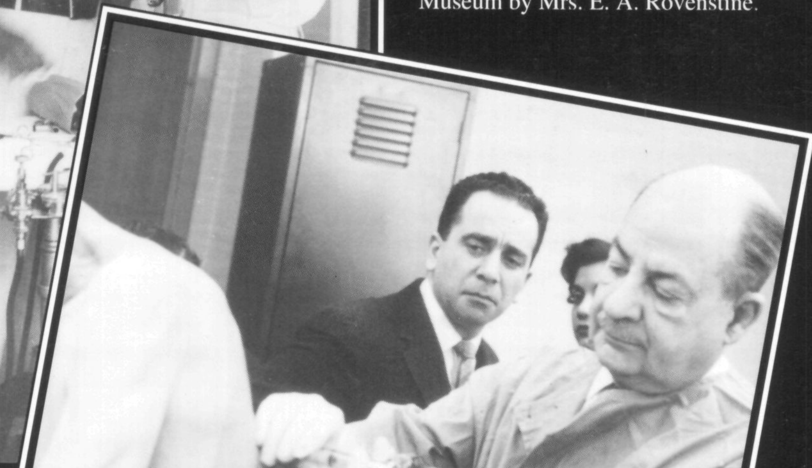
1994

THE ROVENSTINE LECTURES

Part Two



E. A. Rovenstine, M.D., teaching clinical anesthesia during his visit to Olomouc, Czechoslovakia, August 19, 1946. Photo courtesy of Josef Surny, M.D. From photo album presented to the Wood Library-Museum by Mrs. E. A. Rovenstine.



E. A. Rovenstine, M.D. at the Bellevue Hospital, demonstrating to his residents, ca. 1958-59. Photo courtesy of Bertrand Bronner, M.D. of Switzerland, a former Rovenstine resident.

History of Anesthesiology Reprint Series
Volume 24, 1994

The Rovenstine Lectures Part II

In this booklet we offer the second of a series of facsimile reproductions of Rovenstine lectures, first given in 1962 and presented since then at the annual meetings of the American Society of Anesthesiologists. Up until 1972, with few exceptions, the lectures were chosen from among the ranks of leaders in medicine at large and the basic sciences. Subsequently, with the maturation of Anesthesiology into an esteemed specialty, the orators were selected from within our ranks. As such, these leaders in their varied choice of subject matter have painted an engrossing and intriguing portrait of the metamorphosis of their calling. Their presentations as subsequently published in the journal *Anesthesiology* comprised Part I of this series.

Now we retrace the history of the Rovenstine lectureship to its beginnings, to supply not only some of the early lectures but to bring us up to date. As several of the earlier presentations were retrievable only in outline format, namely those of Rahn and Nunn, we are indebted to Professor Raymond Fink for their translation into a fine literary style.

As this two year project comes to a close, the specialty can only be thankful for what this lectureship has accomplished, thus adding to the lustre and lore of Anesthesiology.

Leroy D. Vandam, M.D.
B. Raymond Fink, M.D.

We thank Dr. Alexander Nacht of New York University for contributing the wonderful cover photographs of Dr. E. A. Rovenstine depicting him as a teacher in the later stages of his career.

History of Anesthesiology Reprint Series
Volume 24

The Rovenstine Lectures
Selected Papers
Part II

1. Guyton, Arthur C. *Regulation of Cardiac Output. (1967)*
2. Rahn, Hermann. *Evolution of Gas Transport Mechanisms from Fish to Man. (1968)*
3. Moore, Francis D. *Anesthesia and Surgical Care. (1976)*
4. Siker, E.S. *A Measure of Worth. (1981)*
5. Stead, Eugene A., Jr. *Anesthesiologists Come of Age. (1984)*
6. Annis, Edward R. *Medicine at the Crossroads: What Lies Ahead. (1986)*
7. Nunn, John F. *Balancing the Risks of New Gases. (1987)*
8. Greene, Nicholas M. *The Changing Horizons in Anesthesiology. (1992)*

-1-

REGULATION OF CARDIAC OUTPUT

by Arthur C. Guyton, M.D.

E. A. Rovenstine Memorial Lecture

Introduction

This lecture, established in honor of the late Dr. E. A. Rovenstine, is always one of the highlights of the meeting of the American Society of Anesthesiologists and I am privileged this year to introduce a renowned physiologist, Dr. Arthur C. Guyton, who will discuss "The Regulation of Cardiac Output."

Dr. Guyton has been Professor of Physiology and Biophysics and Chairman of the Department at the University of Mississippi School of Medicine since 1948. He is a master teacher; a respected investigator. His *Textbook of Medical Physiology* is used in medical schools around the world. He is a leader in basic medical research, and his investigations have won him international acclaim. His studies encompass comprehensive approaches to the circulatory system, the respiratory system, and the renal system, together with analyses of the controlling functions of the nervous and endocrine systems.

In 1951 the U. S. Junior Chamber of Commerce named Dr. Guyton one of the Ten Outstanding Young Men in America, and in 1965 he received a First Federal Foundation Award for outstanding service to Mississippi. Dr. Guyton was graduated from the University of Mississippi with special distinction in 1939 and from Harvard Medical School in 1943. He interned at Massachusetts General Hospital. While in a surgical residency there, he contracted paralytic poliomyelitis. During and immediately after his convalescence, he designed aids for the handicapped and, in 1956, received a Presidential Citation for his contributions.

Leonard W. Fabian
General Program Chairman
1967 Scientific Session
American Society of Anesthesiologists

Regulation of Cardiac Output

Arthur C. Guyton, M.D.*

Cardiac output is perhaps the most important single weathervane of functional effectiveness of the circulatory system. Yet, because of difficulties in making repeated cardiac output meaurements, clinical assessment of circulatory function is based instead on less valuable criteria such as venous pressure, color of skin, and so forth. Even so, if one understands the basic factors that regulate cardiac output, he can often estimate it in the various normal and abnormal clinical states with a high degree of accuracy. Therefore, the goal of this article will be to express in terms as essential as possible the factors that play major roles in the regulation of cardiac output.

Basically, three factors are of primary importance in cardiac output regulation: (1) the function of the heart itself, (2) the re-

* Professor and chairman, Department of Physiology and Biophysics, University of Mississippi Medical Center, Jackson, Mississippi.

Accepted for publication October 5, 1967. The original research studies quoted in this paper were supported by Grants-in-aid from U. S. Public Health Service and the American Heart Association.

sistance to blood flow through the peripheral circulation, and (3) the degree of filling of the circulatory system with blood.

Role of the Heart in the Regulation of Cardiac Output

At the outset, we must dispel one of the great myths about the regulation of cardiac output: the myth that the heart itself regulates the normal day-by-day cardiac output. The heart indeed does play a major role in the regulation of cardiac output under some abnormal conditions, but its moment-to-moment, day-by-day role in the regulation of cardiac output is very small.[1] True, the heart *provides* the cardiac output, but other factors, located primarily in the peripheral circulation, do the regulating. This is much the same as saying that the motor of an automobile provides the power to move the automobile, but the accelerator plays a far greater role in regulating its speed.

Permissive Function of the Heart in Cardiac Output Regulation

The normal resting heart of the young adult is capable of pumping about 12 to 15 liters of blood a minute, but the resting cardiac output is only 5 to 6 liters instead of 12 to 15 liters. What this means is that even in the normal resting state the human heart is capable of pumping much more blood than it actually does pump. The only requirement to make it pump an increased amount of blood is that an increased quantity of blood flow into the input side of the heart from the peripheral circulation. To pump up to 12 to 15 liters per minute, the heart does not even have to be stimulated by its nerves.

Therefore, we can state that the heart plays a *permissive* role in the regulation of cardiac output. That is, it *permits* the cardiac output to be regulated at any value between zero and the maximum level that it is capable of pumping. Figure 1 illustrates this basic principle. The top curve, labelled "normal," is one type of Starling's curve of cardiac function, relating cardiac output to right atrial pressure. This figure shows that when right atrial pressure rises to only a few mm. Hg above atmospheric pressure cardiac output will increase to about 13 liters per minute. However, the dashed

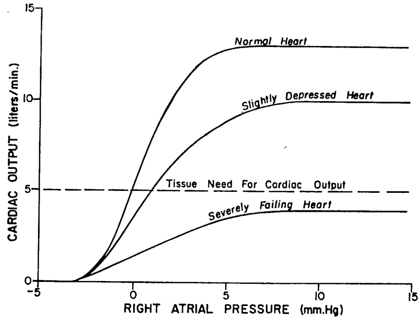


Fig. 1. Cardiac function curves relating cardiac output to right atrial pressure, showing (1) the required normal level of cardiac output and (2) the permissive levels of cardiac output (as expressed by the plateaus of the curves) for the normal heart, the slightly depressed heart, and the severely failing heart.

line illustrates that the normal resting tissue need for cardiac output is about 5 liters per minute; the amount of right atrial pressure required to cause the heart to pump this volume of blood is 0 mm. Hg, almost exactly equal to atmospheric pressure. Thus, the pumping capability of the heart is 13 liters per minute, but the actual amount normally pumped is only 5 liters per minute. The heart permits the cardiac output to be regulated at 5 liters per minute because this is a value considerably below its pumping capability.

Note also the second curve, "slightly depressed heart." This is a Starling's function curve of a heart whose pumping capability has been depressed below normal as a result of a mild to moderate myocardial infarction. In this heart, increasing right atrial pressure to a few mm. Hg above zero will cause cardiac output to increase to a maximum of about 9 liters per minute. Thus, even this depressed heart permits the cardiac output to be regulated at any value between zero and 9 liters per minute. For the normal resting human being this is a completely adequate permissive level of cardiac output, because the required cardiac output is still only 5 liters per minute, well below the permissive level.

On the other hand, observe the lowest curve, "severely failing heart." In this heart, even the upper plateau of the curve never rises to the level of cardiac output that the

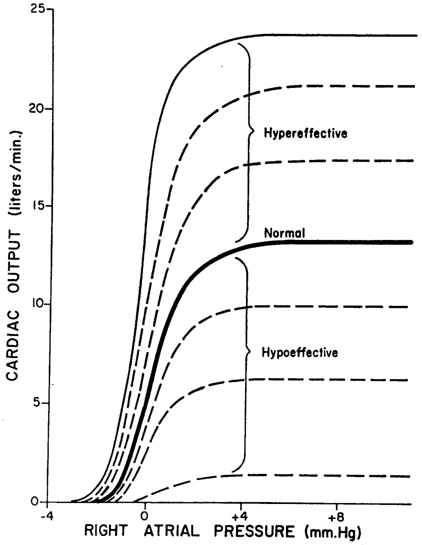


FIG. 2. Family of cardiac function curves for hyper- and hypoeffective hearts. (Reprinted from Guyton: *Cardiac Output and Its Regulation*, W. B. Saunders Co., Philadelphia, 1963.)

tissues require for normal function. As a consequence, the tissues throughout the body suffer drastically, and the functions of some organs, especially the kidneys, become so deranged that a typical picture of circulatory congestion appears. In other words, once the heart has become so weak that it is incapable of pumping the required amount of cardiac output, the permissive level of cardiac output regulation has fallen below the required level. It is with these conditions that the cardiologist is most seriously concerned.

EFFECT OF NERVOUS STIMULATION OF THE HEART

Many accounts, in both old and modern literature, have contended that cardiac output is controlled primarily by nervous stimulation of the heart itself. That is, nervous stimulation theoretically increases the heart's activity, and this in turn increases cardiac output.[2] However, very simple experiments and many clinical evidences prove this not to be true. For instance, complete denervation of the heart, which has been accomplished many times in animals and a few times in human beings, hardly affects the ability to regulate cardiac output.[3] Even a greyhound can run around a racetrack almost as rapidly with his heart denervated as he can when it is completely innervated.[4]

On the other hand, studies of isolated hearts and the heart-lung preparation have demonstrated that parasympathetic inhibition and sympathetic stimulation greatly increase heart rate and at the same time increase pumping capability.[5] Thus, the permissive level of cardiac output regulation is increased.

If we translate this experience in animals to the human being, it means that even though the normal permissive level of cardiac output is only 12 to 15 liters per minute, when the heart is stimulated by the sympathetics (and the parasympathetics are inhibited simultaneously), the permissive level of cardiac output regulation increases to perhaps 25 to 35 liters per minute.

Yet, here again, the fact that autonomic stimulation can increase the *permissive* level of cardiac output to double normal does not mean that the actual cardiac output increases to values far above normal. Instead, the function of the autonomic nervous system in relation to cardiac output regulation is simply to keep the permissive level of cardiac output always above the actual required level. One of the most outstanding examples of this occurs during heavy exercise, for the required level of cardiac output then often increases to as high as 20 to 25 liters per minute, which is far above the 12 to 15 liters of cardiac output that the normal resting heart can pump. Yet, at the same time that the nervous system transmits nerve impulses to the skeletal muscles to cause muscle activity, it also transmits signals by way of the autonomic nervous system to the heart to increase both the heart rate and the strength of the heart muscle.[2] As a result, the permissive level of cardiac output rises from the resting value of 12 to 15 liters per minute to 25 to 35 liters per minute (and perhaps even higher in the athlete). Thus, the permissive level of cardiac output is kept at a value somewhat above the actual required cardiac output.

Hypo- and Hypereffective Hearts

Much of what has been stated above is summarized in figure 2. The curve labelled "normal" is a Starling's function curve for the normal resting heart, relating cardiac output to right atrial pressure. Under some conditions the heart can become much stronger than normal. Autonomic stimulation can cause this, as was pointed out above. Another factor that can increase the pumping capability of the heart is cardiac hypertrophy, which occurs in conditions such as hypertension, athletic training, and patent ductus arteriosus. In figure 2 the curves above the normal curve are labelled "hypereffective," indicating that whatever the cause of increased pumping capability of the heart, whether it be hypertrophy or autonomic stimulation, the permissive level of cardiac output is increased.

The lower curves of figure 2, labelled "hypoeffective," represent cardiac function curves of hearts depressed by any factor that makes the heart a poorer-than-normal pump. These factors include, among others, myocardial infarction, parasympathetic stimulation, valvular heart disease, myocarditis, and congenital heart disease.

Therefore, keeping in mind the curves of figure 2 and remembering that the normal resting human heart is capable of pumping several times as much blood as it is ordinarily called upon to do, one easily can understand the role of the heart in cardiac output regulation.

Role of the Peripheral Circulation in Cardiac Output Regulation

If the heart itself plays only a permissive role, then we must ask the question, what *does*

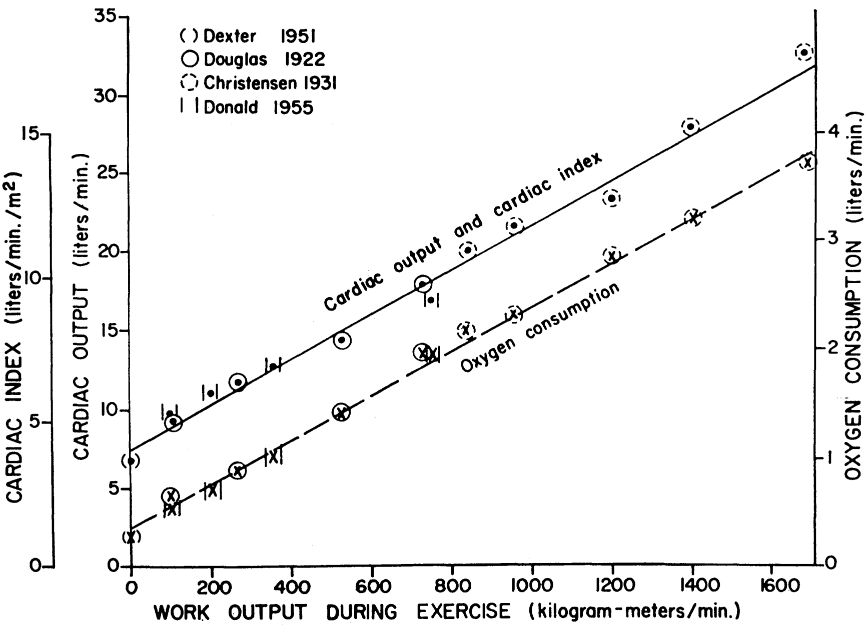


Fig. 3. Relationship between cardiac output and work output (solid curve) and between oxygen consumption and work output (dashed curve) during exercise. Data is derived from studies by Douglas and Haldane (1922); Christensen (1931); Dexter, Whittenberger, Haynes, Goodale, Gorlin, and Sawyer (1951); and Donald, Bishop, Cummings, and Wade (1955). (Reprinted from Guyton: *Cardiac Output and Its Regulation*, W. B. Saunders Co., Philadelphia, 1963.)

regulate cardiac output? The answer is that under most normal physiologic conditions cardiac output is regulated primarily by the peripheral tissues and not by the heart.

Regulation of Cardiac Output by Resistance to Blood Flow in the Peripheral Tissues

Almost every tissue of the body is capable of regulating its own blood flow. Thus, during muscular exercise blood flow through each exercising muscle increases markedly.[6] Likewise, blood flow through the kidney is regulated in proportion to the need for the kidney to excrete certain blood substances.[7] For instance, an increase in blood sodium increases renal blood flow as much as 20 to 40 per cent, or an increase in nitrogenous waste products in the blood can increase renal blood flow 20 to 50 per cent. In the brain, blood flow is regulated primarily by the need for removal of carbon dioxide from brain tissues.[8] The greater the concentration of carbon dioxide, the greater the cerebral blood flow. A high carbon dioxide concentration can double blood flow through the brain.

In general, therefore, one can state that blood flow through each local tissue of the body usually is controlled by some special control system related to the activity of that individual tissue. Obviously, the sum of the blood flows through all the different tissues equals the cardiac output. Consequently, we have, in effect, stated that the cardiac output is controlled by the sum of all the control systems in the individual tissues.

Role of Oxygen in the Regulation of Cardiac Output

For many years it has been recognized world-wide that cardiac output increases almost directly in proportion to the rate of oxygen usage by the body. This is true whether the increased oxygen usage is caused by increased muscular work load, by hyperthyroidism, by dinitrophenol poisoning, etc. Figure 3 illustrates this relationship for persons undergoing different degrees of exercise workload, showing a striking parallelism between increase in oxygen consumption and increase in cardiac output. It is very important to discuss why there is such a parallel relationship between oxygen usage and cardiac output regulation.

On study of blood flow regulation in local tissues, one is immediately impressed with the fact that blood flow through most tissues is highly responsive to changes in local availability of oxygen. This effect is illustrated dramatically in figure 4, a record of blood flow through an isolated hind limb of a dog under several different conditions.[9] After a control blood flow measurement, the blood flow was completely blocked for ten minutes and then reinstituted. When it was reinstituted, the flow increased to approximately four times normal, illustrating that some effect had occurred in the tissues during the ten minutes of ischemia to cause very great dilatation of the blood vessels. This phenomenon is called reactive hyperemia. Ordinarily, the blood flow would have returned to normal in another minute or two, but this leg was perfused for the first ten minutes after the block was over with blood from which all oxygen had been removed. The blood still had all normal nutrients except oxygen; yet blood flow remained four times normal as long as the leg was perfused with this anoxic blood. Then, finally, oxygen was returned to the blood, and blood flow through the limb returned to normal within the next few minutes. This specific experiment demonstrates the high dependence of blood flow regulation in isolated body tissues on oxygen itself.

Critical studies have demonstrated that oxygen is perhaps the most important of all factors that regulate blood flow in skeletal muscles, smooth muscle, the heart, and many other tissues. These tissues represent well over half the body mass, which indicates that a majority of the local blood flow regulation in the body is highly dependent on the amount of oxygen available in the tissues.

The mechanism by which oxygen deficiency in the tissues causes increased blood flow is still cloudy. Many physiologists believe that oxygen deficiency causes release of metabolic endproducts that act directly on local blood vessels to cause vasodilation.[10] One such product that has been mentioned very prominently is adenosine. However, other physiologists believe that the local vasculature requires oxygen to keep its own smooth muscle

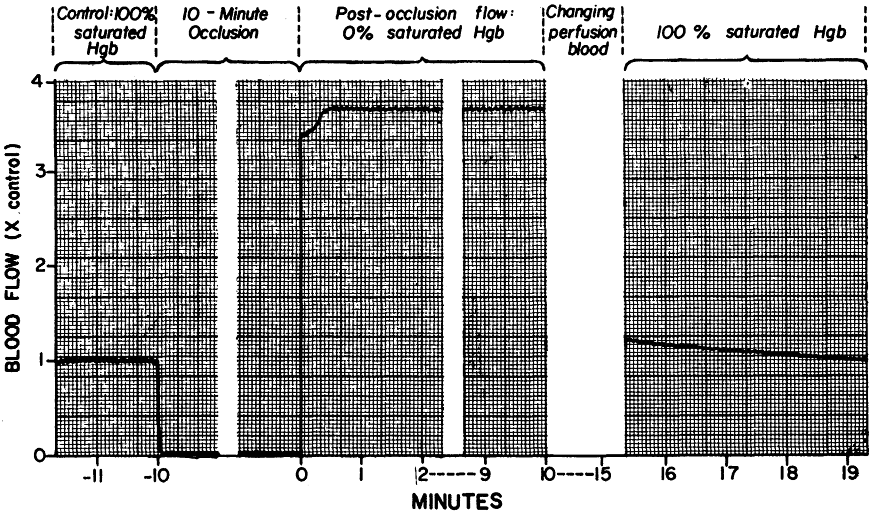


FIG. 4. Blood flow in the hindlimb of the dog following 10-minute occlusion of the blood flow (a) with the hindlimb at first perfused with blood containing no oxygen and (b) later perfused with blood containing normal quantities of oxygen. (Reprinted from Fairchild, Ross, and Guyton: *American Journal of Physiology,* 210: 490, 1966.)

contracted, and that in the absence of oxygen the strength of the vascular smooth muscle becomes diminished, which allows immediate vasodilatation.[11]

Mechanism by Which Tissue Vasodilatation Increases Cardiac Output—the Arteriovenous Fistula as an Example

One of the most instructive experiments for helping to understand the regulation of cardiac output is to study circulatory function at the very moment of opening or closing an arteriovenous fistula.[12] Figure 5 shows such an experiment in which arterial pressure, cardiac output, and fistula flow were recorded. Within a few seconds after opening a very large fistula, fistula flow increased to a value almost equal to the original cardiac output. Within another few seconds, cardiac output had increased almost a similar amount; yet the arterial pressure dropped very slightly.

A few seconds later the fistula was closed, and in a few more seconds cardiac output and arterial pressure were back to normal. This experiment demonstrates a basic principle of circulatory function: any time blood flow is allowed to course directly from arteries to veins, the rate of inflow of blood into the heart increases instantaneously, and the heart (if it has the pumping capacity) automatically responds to the extra flow and pumps the blood back into the arteries. As a result, the arterial supply of blood becomes replenished almost as rapidly as it is removed. The arterial pressure does not fall greatly, but what does happen is an increase in cardiac output almost equal to the extra flow through the fistula.

The same principles apply to the increase in cardiac output when the peripheral vessels in any tissue of the body dilate. Thus, in exercise, the blood vessels of the muscles dilate markedly, and blood flows rapidly from the arteries into the veins and thence into the heart which automatically puts it back into the arteries. Each time vasodilatation occurs in any single tissue, the local blood flow increases and correspondingly increases the cardiac output almost an equivalent amount.

The permissive role of the heart in this mechanism has been described. The normal resting heart has a pumping capacity several times as great as the normal cardiac output so that just as soon as the extra blood flows into the input side of the heart, this reserve pumping capacity of the heart automatically moves the blood back into the arteries. This is what Starling's law of the heart basically states, that the heart will pump whatever amount of blood flows into it (up to its physiological limit) without cauing a significant back-pressure in the veins.

Relative Importance of Venous Resistance and Arterial Resistance in Controlling Cardiac Output

When an arteriovenous fistula is opened, the resistance all the way from arteries to veins is decreased. However, in other conditions venous resistance may become greatly increased while arterial resistance does not change, or, in still other instances, arterial resistance becomes greatly increased without any change in venous resistance. Experiments have shown that there is a marked difference between the effect of arterial resistance and that of venous resistance on cardiac output regulation, which can be explained in the following few paragraphs.[13]

Figure 6A illustrates a simplified schema of the circulation, in which a continuously-active pump pumps whatever amount of blood enters its input side. This blood is pumped into the systemic circulation, represented as a large, distensible bag. The flow of blood into this bag builds up pressure in the bag. It is this pressure in the bag that pushes the blood back through the veins and thence into the pump. If the pump tries to pump more blood than can flow from the bag to the pump, the collapsible veins entering the pump simply collapse like wet straws. Thus, the pump fails to pump any more blood than that amount which is made to flow through the veins by the pressure in the bag. In other words, the heart can pump with extreme activity, and yet the amount of blood that will go around and around the circuit is limited by the pressure in the bag and the resistance from the bag back to the pump. In the circulatory system the entire systemic circulation is the bag, so that all the vessels of the entire systemic system play a role in determining this pressure that will push the blood back toward the heart. This pressure, called the "mean systemic pressure," will be discussed in more detail in following sections of this paper.

The second factor that plays a role is the resistance to blood flow from the bag to the heart. This resistance is an algebraic sum of

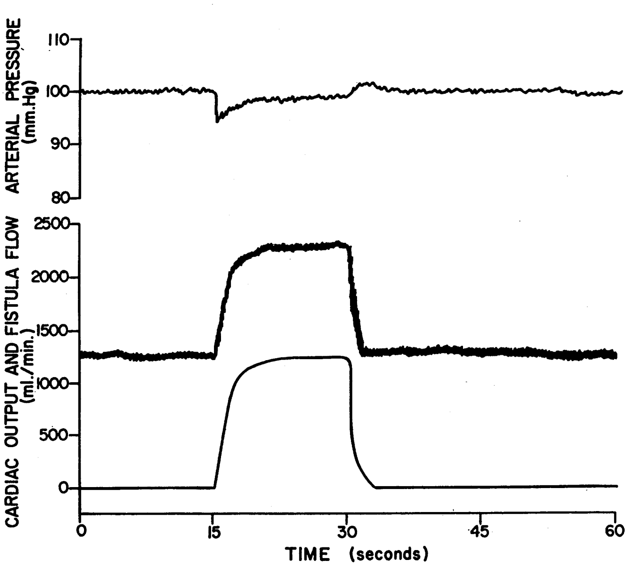


Fig. 5. Effect on arterial pressure and cardiac output caused by suddenly opening and closing an arteriovenous fistula, illustrating that opening of fistula increases cardiac output an amount almost equivalent to the fistula flow.

all the resistances in all the blood vessels of the systemic circulation. However, in summing these resistances, the venous resistance must be weighted to a much greater degree than the arterial resistance. The reason for this can be understood by referring to figure 6*B*, in which the system has been changed to contain two bags, an arterial bag and the venous bag. Arterial resistance is present from the arterial bag to the venous bag, and venous resistance is present from the venous bag back to the heart. Logically, one can see that even a slight increase in venous resistance can cause tremendous storage of blood in the veins and thereby can prevent flow of blood into the heart. On the other hand, an increase in arterial resistance cannot cause much blood storage in poorly-distensible arteries and therefore cannot keep this blood from getting back to the heart. Quantitative experiments have shown that a change in venous resistantce affects cardiac output about eight times as much as does the same change in arterial resistance.[18]

This phenomenon has clinical importance in several ways. For instance, venous obstruction of even the slightest magnitude, such as that caused by tugging on the veins during thoracic operations, can cause drastic reduction in cardiac output. On the other hand, very marked changes in arteriolar resistance generally have very little effect on cardiac output. Indeed, in an experiment in which microspheres were injected into the arteries and then lodged in the arterioles, the arterial pressure of the animal increased to two times normal; yet cardiac output decreased only 10 per cent.[13] This explains why the very high arteriolar resistance found in hypertension is not associated with decreased cardiac output. It also explains why drugs that cause relaxation of arteriolar tone do not necessarily increase cardiac output, for again we can state that changes in arterial resistance and arteriolar resistance play little role in the control of cardiac output. It is either a change in total resistance of the systemic circuit or a change specifically in venous resistance that is the importent factor in cardiac output regulation.

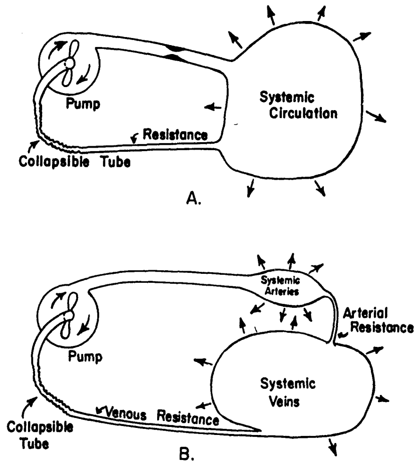


FIG. 6. *A*. Simplified schema of the circulatory system, showing an elastic systemic circulatory "bag," the pressure in which causes blood to flow through the vascular resistance back toward the heart. *B*. Circulatory schema similar to the above but with the peripheral circulatory system divided into two elastic bags, the arteries and the veins, illustrating that venous resistance plays a far greater role in determining venous return than does arterial resistance. (See explanation in text.)

Effect of Blood Volume and Filling of the Circulation on Cardiac Output

Up to this point the discussion has centered primarily around control of cardiac output when various factors affect resistance to blood flow through the peripheral vasculature. However, there is another major peripheral circulatory factor that can affect cardiac output markedly, especially under abnormal conditions. This is the degree of filling of the circulatory system with blood. However, it is not blood volume by itself that determines the degree of filling of the circulation. Instead, it is the *ratio* of blood volume ot circulatory capacity. Furthermore, this ratio can be expressed in terms of the *mean systemic pressure*.[14]

Mean Systemic Pressure and Its Role in Regulation of Cardiac Output

The mean systemic pressure is the pressure that would exist in the entire systemic circulation if the veins and arteries at the heart

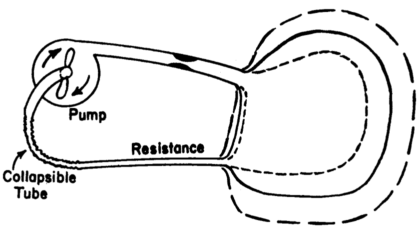


FIG. 7. Schematic illustration of the circulation, showing that the degree of filling of the systemic circulation with blood is one of the major factors that determines flow of the blood from the systemic system into the heart.

should be suddenly occluded and the blood then distributed in the systemic circulation until the pressures were equal everywhere. Obviously, the greater the blood volume or the smaller the capacity of the system, the higher will be the mean systemic pressure. This pressure is a measure of how tightly the systemic circulation is filled with blood, and one can show mathematically that the ability of blood to flow from the peripheral circulatory "bag" back to the heart is affected directly by the level of mean systemic pressure. Without going through the complex mathematics required to prove the importance of the mean systemic pressure in cardiac output regulation, we can explain the basic principle of this by referring to figure 7. To the right, in the figure, the systemic circulation is shown once again as a large bag. However, it is shown in three different states of filling. The normal state is represented by the bag bounded by a solid line, the over-filled state by long dashes, and the underfilled state by short dashes. Let us assume that the heart is pumping blood into the bag continually and that it is then the pressure in the bag that pushes the blood back through the resistance to the heart. If the bag is underfilled, the pressure is too little to push adequate quantities of blood back through all the vessels to the heart. On the other hand, if the bag is overfilled, the pressure will push excessive quantities of blood back through the resisance to the heart. Therefore, we can conclude that if the vascular resistances throughout the circulatory system remain constant, the rate of blood flow into the heart is related directly to the degree of filling of the bag.

Under many abnormal conditions, the degree of filling of the circulatory system is much

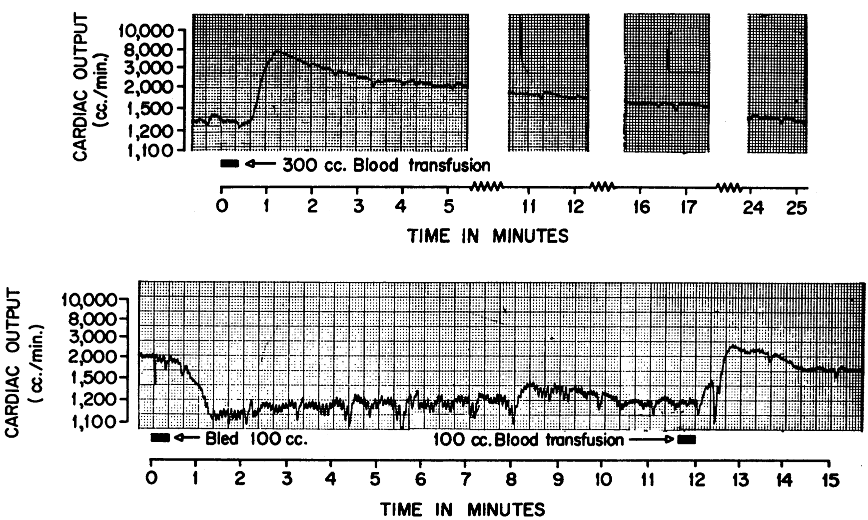


FIG. 8. *A*. Effect of transfusion on cardiac output. *B*. Effect of hemorrhage on cardiac output, illustrating that cardiac output recovery from the effects of hemorrhage is not as rapid as recovery from the effects of transfusion.

more important in the control of cardiac output than is the resistance to blood flow in the vessels. For instance, in shock, the resistance to blood flow may be entirely normal, or sometimes even less than normal, and yet cardiac output will still be low simply because the circulatory systemic "bag" is not filled with enough blood to build up adequate peripheral pressure to make the blood return to the heart.

Effect of Transfusion and Hemorrhage on Cardiac Output

Obviously, the easiest way to increase the mean systemic pressure above normal is simply to increase the blood volume, which occurs when a person is transfused with blood. And one would expect cardiac output to increase rapidly and markedly following transfusion. Figure 8*A* illustrates this effect, showing that a sudden transfusion of 300 ml. of blood into a dog increased cardiac output 300 per cent. However, it will be noted that the cardiac output did not remain elevated for long, but instead fell back toward normal during the ensuing 25 minutes. There are many reasons for this rapid return of cardiac output to normal. First, immediately after the transfusion the circulatory system is literally stuffed with extra blood, and the mean systemic pressure rises drastically. In the example of figure 8*A* it rose from its normal value of about 7 mm. Hg to about 28 mm. Hg. Thus, cardiac output rose approximately the same percentage that mean systemic pressure rose. However, during the ensuing minutes the mean systemic pressure fell rapidly to a value only slightly above normal, for two reasons: (a) the circulatory system becomes stretched to accommodate the increased blood volume, and (b) a major share of the blood volume itself is lost. Thus, large quantities of blood are stored in the liver, spleen, and small veins throughout the body, and large quantities of the plasma portion of the blood leak rapidly out of the circulation into the interstitial spaces and into the abdomen in the form of ascites.[15]

In summary, transfusion increases the cardiac output so long as the mean systemic pressure remains elevated. However, when the circulatory system is overfilled with blood, compensatory mechanisms reduce the mean systemic pressure back toward normal very rapidly, and the cardiac output returns to normal accordingly.

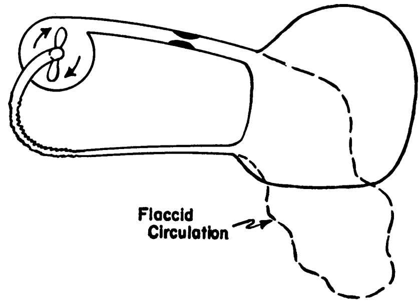


Fig. 9. Schematic representation of the effect of vasomotor collapse on the systemic circulation, showing flaccidity of the peripheral circulation, with insufficient pressure in the peripheral vessels to return blood to the heart.

Following hemorrhage, almost exactly the opposite effects occur, except for one major difference. The mechanisms for returning the mean systemic pressure to normal following hemorrhage are much slower to become effective than is true when the circulatory system is overfilled with blood. Often several hours or even a day or more may be required to bring mean systemic pressure back up to normal. Figure 8*B* illustrates the effect on cardiac output of sudden removal of blood from the circulation, showing that cardiac output does not return to normal easily. Yet, replacement of enough blood to bring the mean systemic pressure back to the normal level will return the cardiac output immediately to normal also.

Effect of the Nervous System on Peripheral Circulatory Regulation of Cardiac Output

Massive stimulation of the sympathetic nervous system, such as occurs when the brain becomes ischemic, can increase the mean systemic pressure from its normal value of 7 mm. Hg to about 18 mm. Hg in 20 to 30 seconds.[16] This occurs mainly because of contraction of the smooth muscle in the vascular walls throughout the body. As a result, the blood pumped by the heart into the circulatory "bag" builds up a much higher pressure in this bag than normally and, therefore, causes greater mean systemic pressure to push the blood through the circulatory resistance to the heart. Therefore, one can see that the nervous system can affect cardiac output by acting on the peripheral circulatory system as much as it can affect cardiac output by acting on the heart.

On the other hand, there are times when the sympathetic nervous system becomes very inactive, rather than overactive, such as occurs in some types of vasomotor collapse. This effect is illustrated in figure 9. In this case, it is immediately evident what is wrong: the blood pouring into the systemic circulation is not enough to distend the system at all; instead, many of the vessels are collapsed, and the pressure generated in the peripheral vessels is too little to push the blood from the peripheral vessels back toward the heart. Under these conditions, hydrostatic factors play a major role in determining the level of cardiac output. Obviously, if the head is down the vessels toward the head will fill much better than will those toward the feet, and since the heart is near the head, the veins entering the heart likewise will become filled reasonably well. Therefore, despite the vasomotor collapse, the cardiac output may still be completely adequate, but this same person in the foot-down position would fill his lower vessels because of hydrostatic factors, while leaving the veins entering the heart completely limp, the result of which obviously would be disaster.

In summary, it is not the blood volume alone that is important in determining the degree of filling of the circulation but, instead, it is the mean systemic pressure that is important, and this is determined by the *ratio* of blood volume to the momentary capacity of the circulatory system.

Role of Blood Volume and Mean Systemic Pressure in Maintenance of Cardiac Output When the Heart Becomes Drastically Weakened

A special feature of a slightly or moderately weakened heart is that it still can pump a normal cardiac output if the right atrial pressure simply rises a few mm. Hg above normal, which was illustrated by the cardiac function curves in figures 1 and 2. One means by which the right atrial pressure can be increased is to increase the mean systemic pressure, which causes increased tendency for blood to flow from peripheral vessels toward the heart. In cardiac failure, this very effect occurs by the following sequence of events: (a) The weakened heart causes the cardiac output to fall. (b) This has drastic mechanical and hormonal effects on the function of the kidneys, reducing urinary output of both salt and water. (c) Because of resulting fluid retention, the total body fluid volume increases, and a small share of this remains in the circulatory system itself, increasing the blood volume. (d) As a consequence, mean systemic pressure increases. (e) This increases the tendency for blood to flow into the right atrium, thus bringing right atrial pressure to a value a few mm. Hg above normal. Often, as a result of this sequence of events, the right atrial pressure finally rises high enough to make even the weakened heart pump a normal cardiac output. Thus, in the early stages of progressive cardiac disease, retention of fluid and expansion of blood volume seem to be an important feature of the compensatory mechanisms to keep the cardiac output normal. Indeed, this stage of compensation occurs so imperceptibly that the person himself usually does not know that it is occurring.

On the other hand, in the late stages of cardiac failure, the weakness of the heart becomes extreme. Precisely the same mechanisms are at play to increase the blood volume, but the maximum permissive level of cardiac output set by the weakened heart is now below that required by the body. As a consequence, cardiac output never rises high enough to return renal function entirely to normal. The kidneys continue to retain salt and water; blood volume continues to increase; mean systemic pressure continues to rise, sometimes reaching three to four times the normal value; capillary pressure continues to rise; and the person becomes progressively more edematous. This is the difficult picture of congestive heart failure, with the heart pumping absolutely as much blood as it can, but even this not enough to bring about reestablishment of fluid balance. Without treatment of the patient, the condition will proceed to death. On the other hand, a cardiotonic drug, a diuretic, or treat-

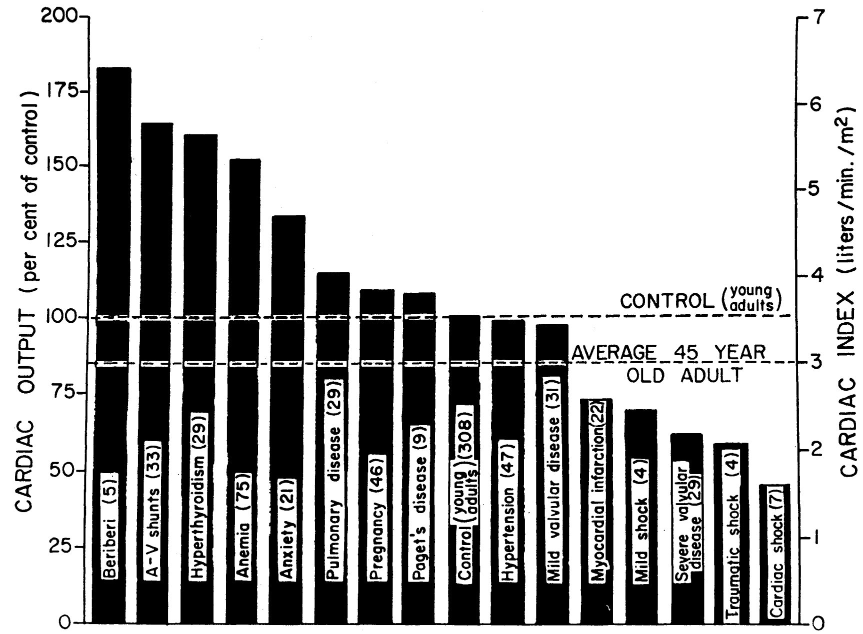


FIG. 10. Cardiac output in different abnormal conditions. The figures in parentheses represent numbers of patients from which the average values were obtained. Constructed from data in the *Handbook of Circulation* (1959). (Reprinted from Guyton: *Cardiac Output and Its Regulation,* W. B. Saunders Co., Philadelphia, 1963.)

ment with bed rest to make the heart a little stronger often can reverse the lethal trend.

Cardiac Output Regulation in Abnormal States

Using the above principles of cardiac output regulation, it becomes very easy to understand most of the clinical abnormalities of cardiac output regulation, some of which are illustrated in figure 10.

In essentially all the states of high cardiac output, its basic cause is decreased resistance to blood flow in the peripheral circulation. Thus, an arteriovenous fistula greatly decreases peripheral resistance. Likewise, hyperthyroidism, anemia, Paget's disease, beriberi heart disease, and pregnancy all decrease peripheral resistance. In hyperthyroidism, this decrease is caused by excessive use of oxygen in the tissues and resultant hypoxic vasodilatation. In berberi, it is caused by thiamine deficiency. In Paget's disease, it is caused by a multitude of small vascular shunts from arteries to veins in the bones. In anemia, the decreased resistance is caused by two factors: decreased viscosity of the blood itself, and some degree of vascular dilatation caused by relative hypoxia of the tissue.

Another condition that can cause increased cardiac output (as described above) is excessive blood volume caused by transfusion, although the increased cardiac output caused by this does not last long because of compensatory mechanisms.

On the other hand, most of the factors that decrease cardiac output to below normal are related to one of two conditions, either a weak heart that lowers the permissive level of cardiac output or a decrease in mean systemic pressure. Thus, in cardiac disease—whether it be caused by myocardial infarction, terminal stages of valvular heart disease, or any other condition—cardiac output can fall considerably below normal for days or weeks at a time, but once it falls below approximately two-thirds normal, one can expect an early demise.

Likewise, one readily can understand that hemorrhage, which reduces the mean systemic pressure so much that blood will not flow from the peripheral circulation back to the heart, can cause all degrees of decreased cardiac output. Also, neurogenic shock, characterized by flaccidity of the peripheral circulation, can reduce the mean systemic pressure enough, despite normal blood volume, that cardiac output can fall to lethal levels, especially if the person is in a head-up position.

Summary

Under most normal conditions, cardiac output is regulated mainly by the tissues, each tissue regulating its own blood flow, cardiac output being the sum of the flows through all the peripheral tissues. This mechanism works very simply as follows: When the vasculature of the tissues dilates, blood flows rapidly from the arteries to the input side of the heart. The heart then automatically pumps the blood immediately back into the arteries, thereby keeping the arterial blood reservoir replenished with blood as rapidly as it runs off through the tissues.

The heart plays a permissive role in the regulation of cardiac output. The normal human heart under resting conditions can pump perhaps 12 to 15 liters per minute, and when stimulated by the autonomic system, perhaps 25 to 35 liters per minute. Rarely does the cardiac output actually rise to the maximum levels. Thus, the heart *permits* the cardiac output to be regulated at any value between zero and its permissive level. Except for this effect, the heart plays a secondary role in cardiac output regulation unless it becomes too weak to meet the demands of the body.

The two principal factors that determine the rate at which blood will return to the heart from the peripheral circulation are (1) the degree of vasodilatation of the peripheral vasculature, especially of veins but to a lesser extent arteries as well, and (2) the degree of filling of the circulatory system, which is expressed as the mean systemic pressure. Either a decrease of resistance in the vasculature or an increase in the mean systemic pressure will increase cardiac output.

References

1. Guyton, A. C.: Circulatory Physiology: Cardiac Output and Its Regulation. Philadelphia, W. B. Saunders, 1963.
2. Rushmer, R. F., and Smith, D. A., Jr.: Cardiac control, Physiol. Rev. **39**: 41, 1959.
3. Warner, H. R., and Toronto, A. F.: Regulation of cardiac output through stroke volume, Circ. Res. **8**: 549, 1960.
4. Donald, D. E., and Shepherd, J. T.: Initial cardiovascular adjustment to exercise in dogs with chronic denervation, Amer. J. Physiol. **207**: 1325, 1964.
5. Sarnoff, S. J.: Myocardial contractility as described by ventricular function curves, Physiol. Rev. **35**: 107, 1955.
6. Barcroft, H., Dornhorst, A. C., McClatchey, H. M., and Tanner, I. M.: On the blood flow through rhythmically contracting muscle before and during release of sympathetic vasocontrictor tone, J. Physiol. **117**: 391, 1952.
7. Smith, H. W.: Principles of Renal Physiology. New York, Oxford Univ. Press, 1956.
8. Lassen, N. A.: Autoregulation of the cerebral blood flow, Circ. Res. **15** (Suppl. I): 201, 1964.
9. Fairchild, H. M., Ross, J. M., and Guyton, A. C.: Identity of oxygen lack hyperemia and reactive hyperemia, Amer. J. Physiol. **210**: 490, 1966.
10. Berne, R. M.: Metabolic regulation of blood flow, Circ. Res. **15** (Suppl. I): 261, 1964.
11. Guyton, A. C., Ross, J. M., Carrier, O., Jr., and Walker, J. R.: Evidence for tissue oxygen demand as the major factor causing autoregulation, Circ. Res. **15** (Suppl. I): 60, 1964.
12. Guyton, A. C., and Sagawa, K.: Compensations of cardiac output and other circulatory functions in areflex dogs with large A-V fistulae, Amer. J. Physiol. **200**: 1157, 1961.
13. Guyton, A. C., Abernathy, J. B., Langston, J. B., Kaufmann, B. N., and Fairchild, H. M.: Relative importance of venous and arterial resistances in controlling venous return and cardiac output, Amer. J. Physiol. **196**: 1008, 1959.
14. Guyton, A. C., Lindsey, A. W., and Kaufmann, B.: Effect of mean circulatory filling pressure and other peripheral circulatory factors on cardiac output, Amer. J. Physiol. **180**: 463, 1955.
15. Guyton, A. C., Batson, H. M., Jr., and Smith, C. M., Jr.: Adjustments of the circulatory system following very rapid transfusion or hemorrhage, Amer. J. Physiol. **164**: 351, 1951.
16. Guyton, A. C., Satterfield, J. H., and Harris, J. W.: Dynamics of central venous resistance with observations on static blood pressure, Amer. J. Physiol. **169**: 691, 1952.

-2-

EVOLUTION OF GAS TRANSPORT MECHANISMS FROM FISH TO MAN

by Hermann Rahn, M.D.

ROVENSTINE LECTURE

American Society of Anesthesiologists

Washington, D.C., October 22, 1968

Evolution of Gas Transport Mechanisms from Fish to Man

Hermann Rahn, M.D.

IT IS WITH GREAT RESERVATION, hesitation, and a spirit of humility that I address you today as the Rovenstine Lecturer. I am indeed deeply honored by this invitation, particularly so since I am not an Anesthesiologist.

"Rovey," as he was affectionately called, was one of your great figures, a pioneer, an inspiring teacher who did so much for modern and progressive anesthesiology. Thus it would be appropriate, on occasions such as this, to choose a lecturer who would emphasize the important areas of research and practice which lie ahead of you. In this regard I must disappoint you. In fact I have chosen to go the other way and elected to momentarily stop the wheels of progress.

In our mad scramble to roll back the large frontiers of science let us pause long enough to see where we are going. Let us re-examine the basic principles upon which our modern concepts of gas transport are constructed. Let us make sure that we have the right cornerstones, for all of us are daily building larger and more sophisticated structures on top of them. Have we built on rock or sand?

You will smile, for in this short time I would like to re-examine the inter-regulation of pulmonary ventilation, cardiac output and acid-base balance. My interpretation and answers however will not be derived from experiments designed by man, but from experiments of nature.

I wish to tell a story, parts of which may not please you. Your reaction will probably be the same as that of a certain mother who listened to her daughter's story: One day the daughter was walking in the woods when she heard a pleading voice calling to her. "Please come and pick me up." She searched and searched and finally found a beautiful frog sitting on a rock. "Please pick me up," he pleaded. "I am not really a frog at all, but a handsome prince in disguise. If you will only take me home and put me under your pillow, it will break the charm." So she did. The next morning when her mother opened the bedroom door she found her daughter sleeping with a good-looking young man. And, you know, to this day her mother has never believed that story.

Well, *my* story starts by climbing a mountain. If we go high enough we see the lakes which represent the remains of our ancestral past. The stream that represents our true ancestors was both deep and fast and left behind the eddies which we still see today. These eddies are nature's experiments, evidence of animals which tried but did not make it. But for us today they are convenient sign-posts of what the ancestral stream might have been like. Probably the most difficult period was the transition from water to land, and I shall say more about this later.

Let us now examine the basic plan of the gas transport system. Two convection pumps separated by a diffusion path: Convection-diffusion-convection-diffusion. It fits all vertebrates: fish pump water instead of gas. The overall design and purpose serve only one primary goal, namely, the optimal maintenance of the oxidative enzyme system in the mitochondria. In order to do so the transport system must provide two conditions (1) delivery of minimal O_2 pressure of 2-3 mm Hg and (2) maintain an optimal H+ concentration. Let us start with a description of the turnover rate of these two pumps in different animals. Catheters in the pre-gill and post-gill vessels allow one to measure the cardiac output in the fish by means of the Fick Principle.

Catheters in the gill chamber allow one to sample "alveolar" water concentration and therefore ventilation — Fick Principle. In order to make valid comparisons I had divided the minute ventilation by the oxygen consumption: ml ventilation/ml M_{O_2}. For resting man this is 20 ml ventilation/1 ml M_{O_2}. The ventilation pump is thus extremely sensitive to the O_2 concentration of the environment. It is the first link in the O_2 transport system and obviously must assure delivery of an adequate pressure.

There can be little question that the O_2 concentration of the medium controls the ventilation pump. Let us take the same approach to the blood pump. Here there is not much difference between fish and man. An anemic man resembles a polycythemic fish! What is particularly important is that the changeover from aquatic to air breathing appears to reflect little change, if any, in the blood pump. Cold blooded animals, air or water breathers, have a low hemoglobin concentration and therefore a slightly higher relative blood flow. The burden of responding to the O_2 concentration is placed on the shoulders of ventilation. Once the ventilation has delivered sufficient O_2, the circulatory pump has not had to respond over the last 400 million years. The effect of the hemoglobin concentration on the relative cardiac output is relatively inconsequential.

The Constant Milieu of the Extracellular Fluid

The rough description given here provides some insight into the turnover rates of these two pumps, which together with the two diffusion pathways are presumably able to deliver an adequate O_2 pressure at the mitochondria. The next important question concerns itself with the maintenance of an optimal pH. Obviously the P_{CO2} is quite variable. In fish this is about 2-3 mm Hg, in amphibians it may vary from 5 to 30 depending on the body temperature. In turtles it may vary from 12 to 60, and in mammals and birds it appears to be generally 35 to 45. The bicarbonates are equally variable; and when one looks at blood pH of lower forms recorded in the literature, the results seem equally confusing.

The Effect of Temperature and pH

We finally embarked on a project to determine the normal pH of cold blooded animals in the laboratory. We took extreme care to do this in awake, unanesthetized animals and after several days of acclimation to various temperatures. All determinations were made at that temperature and proper buffer corrections were made. These experiments have now been made on many species over many years.

Are the colder animals really alkalotic? The answer is no. They are no more alkalotic with a pH of 8.0 and 5°C than you or I, when we establish the proper reference. This reference for every temperature is the *neutrality of water:* It is pH 7.0 at 24°C, but 6.8 at 37°C and 7.4 at 5°C.

What is amazing is that the relative alkalinity of the blood of all the animals is constant with respect to the neutrality of water. There is a constant pH difference of 0.6 units. If we know the pH we can also plot the pOH. The change in pH parallels the change in pOH. This means only one thing. The ratio between OH^- and H^+ ions is constant. Since we are normally on the alkalotic side, we have more OH^- ions. The constant difference between pH and, pOH implies a constant ratio of 20 OH^- ions to one H^+ ion.

The implications of this concept are rather far reaching. *What I am suggesting is that pH itself is not regulated, nor is it the H^+ concentration. What is preserved and regulated is the relative alkalinity and this is expressed as the ratio between OH and H ions. This is the common denominator for all vertebrates at all temperatures. At our body temperature this happens to correspond with a pH of 7.4.*

The P_{CO2} and HCO_3^-

You will ask what happens to the P_{CO2} and H_{CO3}^- at different temperatures? I will supply one typical example. You now see that every temperature requires a different PCO2, H_{CO3}^- and pH. What is constant? Nothing! The only thing which is preserved is the ratio of OH to H.

I am therefore forced to conclude that the notation of pH is an invention of physiologists and biochemists. The pH notation is not a natural quantity of any biological importance. We may use the pH notation in a practical sense but we must not therefore automatically infer that this is a natural quantity which is biologically sensed. These are indeed fighting words!

Regulation of Transport Mechanism in Vertebrates

I will now summarize my impressions of the overall regulation of the gas transport mechnism in all vertebrates. The respiratory center imposes a ventilatory drive which in turn determines the P_{O2} and P_{CO2}. The P_{O2} of the tissues must be adequate (at least 2-3 mm Hg). If it is below that, we have hypoxia and in some manner this is fed back to the center.

The absolute P_{CO2} is of no consequence as long as the kidneys are able to preserve a H_{CO3}^- which provides the OH^-/H^+ ratio of 20:1. If this is not maintained this information is fed back to the kidney and the respiratory center. Therefore as long as these two values, tissue P_{O2} and OH/H concentration ratio, are preserved, the absolute P_{CO2}, CO_2 content, H_{CO3}^-, P_{O2}, hemoglobin, and saturation can vary widely as individual adaptations to the external environment. The P_{CO2} may be an important messenger — but it is secondary! We do not have to resort to lower animals to back up this statement. We can find support for it in normal man who has lived for centuries at altitude. We know that his pH is 7.4, his OH/H ratio is the same as ours at sea level, and his tissue oxygen pressure is obviously adequate when we watch his remarkable physical performance at altitude. However, his P_{CO2} H_{CO3}^-, C_{O2} content, hemoglobin P_{O2} and saturation are all quite abnormal by sea level standards.

The Acquisition of Lungs

I would now like to explore with you the problem of relinquishing gills and acquiring lungs. After pumping water through gills for millions of years it must have been a great relief to get a taste of that oxygen-rich medium called air. Once you acquired the habit it was difficult to kick it.

But these joys were short-lived. The oxygen content was so great that one could now afford to reduce ventilation enormously and still provide the blood with sufficient O_2. As a consequence, the CO_2 tensions rose and the *first big problem* which confronted the explorer was how to compensate for a respiratory acidosis of major proportions. Let us look at this problem quantitatively and compare the behavior of respiratory gases in air and in water. We take it for granted that when O_2 is removed and replaced by CO_2, the O_2 pressure falls by the same amount as the CO_2 pressure of alveolar gas rises.

When we inspire air the RQ is 0.8. When the alveolar O_2 is 100, the P_{CO2}, is 40 mm Hg. It must be that way; it cannot be any different. However, in air-saturated water the O_2 and CO_2 pressures no longer behave in the same manner. Now for equal units of O_2 and CO_2 exchange, for every 25 mm Hg fall in O_2, CO_2 rises not 25 mm Hg but 1 mm Hg, owing to the large solubility differences. In the air breather, the P_{CO2} is 40 mm Hg, in the water breather, 2 mm Hg. Let me also remind you that the O_2 tension in air will be maintained by a ventilation which is 20 to 30 times less than that in water.

What are you going to do when you shift from water to air?

1. You can suddenly raise your H_{CO3}^- to appropriate levels to match the rising CO_2.

2. You can also prevent your CO_2 from rising by ventilating air at the same rate as you did the water — but this requires lungs which are mechanically able to do this.

3. You can invent another system for lowering the P_{CO2} which does not involve the lung. This is skin circulation — where convection currents do the work.

Consequently, Dr. Garey and I asked the following question. If air breathing did impose such restraints, as we imagined, how did the first air breathers cope with the respiratory acidosis?

1. Did they let their CO_2 rise?

2. If so, were they able to compensate with H_{CO3}^- ?

3. Were these primitive lungs able to ventilate sufficiently to maintain a reasonable CO_2 or did they have to use skin CO_2 excretion?

These questions became particularly poignant when we read a certain publication which thought that this transition was extremely simple. There was now only one thing to do. That was an on-the-spot investigation of an air-breathing fish. So last summer Dr. Garey and I flew down to the Amazon to look at the air-breathing electric eel.

Probably the most important concept we learned was that a primitive lung could extract large amounts of O_2 from the air by intermittent breathholding. But this would raise CO_2 to intolerable levels. Therefore another device was called upon for CO_2 elimination. This was skin excretion of CO_2. High perfusion of a naked skin was the price one had to pay for acquiring a primitive lung.

Then we remembered that the frogs and salamanders were doing exactly this. This had been well established. However, if you must excrete CO_2 through the skin, it requires a certain degree of capillary exposure to the air. This means nakedness. In other words it was not possible during this period to cover your exterior with armor.

This obviously was particularly embarrassing to the emergence of animal life upon land. It prohibited the development of epidermal protection at a time when it was sorely needed — to prevent dessication and provide physical protection against the physical land objects over which these animals had to crawl — no longer supported by the buoyancy of the water. It was not until the modern lung could completely take over the maintenance of CO_2 tension that armor could reappear again, and thus complete the true conquest of land and the dry atmosphere. This was in the reptilian stock, and further led to feathers and hair. In this sense homeothermy had to await the development of the modern CO_2 regulator — the present lung.

Amphibian Metamorphosis

If these large changes in P_{CO2} and H_{CO3} took place in air-breathing fish — what happened in amphibians? The tadpole is a gill breather; the adult a lung breather. We had studied the adult frog with its high P_{CO2} and H_{CO3}^-. What would the tadpole show? Dr. Erasmus learned to take blood samples from these tiny creatures.

At the normal pH their P_{CO2} is 2 mm Hg and HCO_3^- less than 4. Just like a fish.

Sometime during metamorphosis a tremendous change must take place as predicted by the gas laws.

Chick Embryo Development

Even more surprising was Dr. Erasmus's investigation of the chick embryo. For 9 days it behaves like a fish. Then a dramatic rise in CO_2 and H_{CO3}^- occurs, all this going on while the lung is developing but not functional. This organ does not inflate with air until the day before hatching. Here is an uncanny anticipation and preparation for a functional lung. In this case we must ask what triggers the onset of this compensated acidosis. It suggests a long ancestral hangover — a recapitulation of its phylogeny. This phylogeny is recapitulated in the development of the frog over a period of 3 years. In the chick in 21 days. As I see it we have here a beautiful example of a functional recapitulation of the phylogenetic traits of our ancestors, the shift from water to air respiration.

Summary of Acidosis

I hope I have convinced you that the acquisition of the lung was not a simple matter. The price for initiating it was high indeed. First, it required the loss of armor — nakedness, at a time when it was sorely needed. Second, it required a kidney which could respond to the severe rise in CO_2 by raising the H_{CO3} level. The problem was not one of getting enough O_2. Actually it was a problem of too much O_2 followed by hypoventilation and acidosis, not unlike that of a severely acidotic patient who is given O_2 to breathe.

In summary, in spite of the trials and tribulations of our ancestors in their literally thousands of different experiments in adapting their gas transport to an ever changing environment, it is striking to realize that the basic structural and functional plan was never altered and that over the time course of vertebrate evolution it was the *milieu intérieur* which remained stable and constant, namely: (1) the P_{O2} of the tissues and (2) the relative alkalinity of the extracellular fluid. All other blood characteristics, P_{CO3}, H_{CO3}, hemoglobin, Hb_{O2}, etc., were secondary and reflected special adaptations to the environment. However, this concept does require that we give up the notion that pH, per se, is a natural quantity which is sensed and regulated. pH is a useful tool for measurement, yes, but it must be translated into its biological meaning, which is neither pH nor H ion concentration.

In 1908, sixty years ago, L.F. Henderson wrote his impressive treatise on acid-base regulation which became the foundation for our present practice. In this he clearly stated that when you change the body temperature you must also change the pH if you are to preserve the same balance between H and OH ions. It is 60 years later that I have finally learned his lesson, which appears still to have escaped most of us.

-3-

ANESTHESIA AND SURGICAL CARE

by Francis D. Moore, M.D.

Anesthesiology
48:125–138, 1978

Reprinted from: ANESTHESIOLOGY, Vol. 48, No. 2, February 1978

American Society of Anesthesiologists Rovenstine Lecture—1976:

Anesthesia and Surgical Care

*Francis D. Moore, M.D.**

One Surgeon's Introduction to Anesthesia

The nature of the anesthesia experience is a major determinant in the quality of surgical care. It is my purpose here to examine manpower in these two professions, so closely intertwined, and to develop some first estimates of national and regional manpower norms and ratios for surgical and anesthesia personnel. Such estimates, however tentative, may be useful at a time when the analysis of health manpower and the delivery of surgical and anesthesia care are at the forefront of our national thinking. Methods, concepts, or ratios developed here may stimulate others, better qualified than I, to explore further the interrelationship of our two professions. Before embarking on these data, a personal word is in order.

I want to thank the American Society of Anesthesiologists for the honor of presenting this annual lectureship to celebrate the memory of the late Dr. Emery Andrew Rovenstine (1895–1960), for many years Professor and Head of the Department at the New York University–Bellevue Medical Center. To many scholars, he was one of our first truly academic anesthesiologists. He had been a resident of Dr. Ralph M. Waters in Wisconsin, and he himself made many contributions to anesthesiology, all of which improved the care of surgical patients.[1–4] He was particularly instrumental in the development and use of cyclopropane, an agent we now look upon as hazardous. Yet, at the time that Dr. Rovenstine worked on this anesthetic (about 1934), anesthesiology sorely needed some way out of the "Valley of the Shadow" of ether and chloroform, in which it had wandered for almost 90 years.

From Rovenstine's development of cyclopropane came an increasing interest in other possible inhalation agents, and their initial use. At the same time he was working on improved anatomic methods for conduction anesthesia. This development of regional techniques was one of his major contributions to anesthesiology, a trend in which he followed the footsteps of his surgical predecessor in the field, Dr. William S. Halsted, who had introduced local anesthesia by nerve block with cocaine. Many surgeons came to study with Rovenstine; surgeons and anesthesiologists joined in the further development of regional block for major intracavitary surgery. To understand this one must realize that in the 1930's, before the development of endotracheal intubation, there were still severe hazards involved with the inhalation agents, hazards that are a rarity today. Dr. Rovenstine explored, and was among the first to perfect, regional block for major thoracic surgery.

Dr. Rovenstine was also deeply concerned with standards for training in anesthesiology and the organizational relationships between anesthesiologists and surgeons. In 1940, he published "The Economics of an Anesthesia Service in a Large Municipal Hospital," a work that bears study today.[1] It was my pleasure to meet Dr. Rovenstine on one occasion, at a meeting of The Society of Clinical Surgery at Bellevue Hospital, with Dr. John Mulholland. Dr. Rovenstine showed both his work and his techniques, as well as his characteristic warmth, charm, and hospitality.

My own inspiration in anesthesiology has arisen from the three men with whom I have worked most closely throughout my life.

The late Dr. Henry K. Beecher, long a member of this Society, taught me anesthesia, if such is an appropriate term for the humble learning process of a young surgical "pup" starting his internship. In later years Dr. Beecher took a keen interest in my

* Elliott Carr Cutler Professor of Surgery, Harvard Medical School; Surgeon, Peter Bent Brigham Hospital; Consultant, Sidney Farber Cancer Institute, Boston, Massachusetts.

Key words: Anesthesiology; Anesthesiologists; Manpower, anesthesiologists; Manpower, nurse anesthetists; Manpower, residents.

Address reprint requests to Dr. Moore: Department of Surgery, The Countway Library, 10 Shattuck Street, Boston, Massachusetts 02115.

0003-3022-78-0200—0125$01.20 © The American Society of Anesthesiologists, Inc.

work as one of the younger members of the attending staff at Massachusetts General Hospital, where I had the pleasure of working intimately with him for ten years both in clinical work and in research. He was a remarkable individual who made many contributions, not the least of which was his last: a heightened awareness of the ethical problems concerned with experimentation in human subjects.[5]

The second influence in my knowledge of anesthesia was Dr. William S. Derrick, now of Houston, Texas, for several years the Chief Anesthesiologist of the Department of Surgery at the Peter Bent Brigham Hospital. Although the Brigham had enjoyed scholarly physician anesthesia under Dr. Walter Boothby 30 years before,[6] there had been a long period of unsupervised anesthesia; this had an adverse impact on the development of both thoracic and cardiac surgery at the Brigham. Dr. Derrick reversed this trend and showed a constant devotion to the problems of his patients and his surgical colleagues.

To continue on this personal note for a moment, Dr. Leroy D. Vandam, the man with whom I have worked closely for more than a quarter of a century, is the third of my anesthesiology colleagues. Dr. Vandam's work on hazards of spinal anesthesia and his work on visceral sensation and its effect on the circulation must be regarded as major advances. But his great contribution has been the establishment of a superb academic department with its key emphasis on the human factor of patient contact, follow up, and student inspiration, and his conviction that anesthesiology is a very humanistic aspect of the practice of medicine, in addition to its well known features as handmaiden to the surgical patient, and applied pharmacology. In addition, Dr. Vandam as Editor of ANESTHESIOLOGY made a major contribution to the art and science of the practice of anesthesia by making this journal a first-rate and respected scientific publication.

Dr. Vandam's Division was part of our Department of surgery until 1970. Although I had always regarded anesthesiology as a part of surgery, I came to recognize and accept, even if I did not welcome, the advent of a new era in which anesthesiology has been separated in its university organization from surgery, from medicine and from pharmacology.

All three of these men established an indelible imprint of the relationship of anesthesia to surgical care and their inseparable mission in the care of the sick.

The Image of the Profession

Dr. Rovenstine might have been surprised by, and possibly disapproved of, the current devotion of scholars to the sphere of sociology and economics of medicine; but the concern was no stranger to him. During World War II there was a period of remarkable expansion of surgery, of the scope of surgery, and after the war an ever-widening distribution of surgeons. At this time Dr. Rovenstine recognized the need to clarify anesthesiology–surgery relations and the essentially institutional nature of the practice of anesthesia. He wrote[7]:

> The anesthesia service functions as a unit in hospital care, not as an individual practicing in a hospital. It cannot be denied that few people go to an anesthetist for anesthesia today. They simply go to a hospital. . . . This situation, except in some few isolated instances, has been tolerated with polite indifference or welcomed by the public, the profession, and hospital administration. . . .

He indicated that this situation may appear undesirable to those whose view of medical practice worships the conventional tradition of solo private fee-for-service practice based on an individual office. He sensed that this value judgment might not apply to anesthesia. He continued:

> . . . principles defended by medicine are tenable so long as their ultimate objective is to improve the quality of medical care for the ultimate benefit of the sick.

In his view the institutional base for anesthesia was no disgrace; indeed it was essential to its maximum public service.

In recognizing the institutional obligation of anesthesiology, Dr. Rovenstine was giving early recognition to a phenomenon that is now shared to a remarkable extent by three other important branches of our profession: radiology, pathology, and rehabilitation medicine. These are four branches of medicine without which the physician, surgeon, and pediatrician could not practice. Their importance is unquestioned. It is not surprising that they are based on the public institution required for their practice.

These four branches of our profession all share certain characteristics. They require a hospital for their practice. Second, they are areas of medical work in which the referral of the patient is from other physicians and patient contact is episodic. Although both of these might seem to be negative factors, or undesirable in the eyes of those who view medicine only in a conventional framework, these very qualities make these fields of work among the most demanding of any in medicine.

Finally, these four professions (anesthesiology, radiology, pathology, and rehabilitation medicine) are often established as distinct hospital departments. They operate within what might be termed a monopoly of practice in the care of patients within that hospital. It is a rarity for a surgeon operating in hospital A to seek the assistance of a full-time anesthesiologist from hospital B. We are apt to forget that the same thing often applies to surgery. The neurologist in hospital A who seeks operation will consult the neurosurgeon of hospital A rather than a more distant colleague from hospital B.

Although many anesthesiologists work in several hospitals, and most are on a fee-for-service basis, the institutional responsibility remains clear; each hospital large enough to have an identifiable department or division for anesthesia services tacitly assumes that the head of that unit will be responsible for anesthesia services throughout the hospital.

Because of this hospital-wide responsibility, the anesthesiologist and his department must supply continuous service 365 days and nights a year. If such service is not provided, is of poor quality, or is insufficiently adaptable to the many needs of surgical patients, rectification is usually sought by changing the leadership of the department. This again points out the assumption of hospital-wide responsibility for anesthesia service. Rather than regarding this as an undesirable feature of anesthesiology as a profession, it is my own belief that it should be appreciated as an extremely demanding responsibility, and a form of medical practice placing it at the highest level of public service.

Whether or not a separate professional fee is collected for each service by the physician is immaterial in the social relationship: high-quality care with independent thinking is a feature of practitioners of high standards, whether they are working as solo practitioners, on a group-practice salary (a frequent practice in both surgery and anesthesia) or on institutional salary. The anesthesiologist provides "hospital professional consultant services"; and the fact remains that for most anesthesiologists there is a clear obligation to provide the highest quality of service for all the patients and staff of a single institution.

The management of intensive care, respiratory care, resuscitation, consultation on intractable pain problems, and a variety of additional services enriches and widens the professional activities and intellectual scope of anesthesiology; the institutional relationship is only heightened thereby.

The Relation of Anesthesiology to Surgery

For analysis of professional work in this country, physicians can be conveniently divided into three groups according to their relationships to hospitals as institutions, and the natures of their referral services. The first group, the "Hospital Professional Service Group," includes the four services already mentioned (anesthesiology, radiology, pathology and rehabilitation medicine). These services are primarily based upon individual hospitals, and the patients are referred to them by other physicians almost exclusively. Second is the "Consultant Group," including surgery and those branches of medicine and pediatrics (*e.g.*, endocrinology, cardiology) that are highly specialized fields, and for which hospitals are essential for practice; referral is both from patients and from other physicians. Third is the "Primary Care Group" or "access physicians" in primary care medicine, often working outside the hospital framework, and providing continuous care to individuals and families over prolonged periods; referral will usually be via other patients.

Among these three categories of physicians, surgery and anesthesiology are more closely intertwined than any other two branches of the medical profession.

I would estimate that 90 to 95 per cent of the work of every anesthesiologist is concerned with the work of a surgeon. The in-hospital operative work of the surgeon is at least 90 per cent involved with the work of an anesthesiologist. The exceptions to the interrelation are those occasions when the anesthesiologist is working on pain problems or respiratory care supervision and those situations in which the surgeon is providing the anesthesia himself, as a regionsl block.

For this reason, the ratio of surgeons to anesthesiologists and to all others providing anesthesia services is an important number in medical manpower. Recent studies from the anesthesia study groups have added important data in this field, and form the basis of many of my tabulations.[8–16]

There are analogous intertwinings of other pairs of professions in medicine, but none of them quite as close. Psychiatry and neurology have worked closely together for many years, but about 40 years ago they began to diverge in their activities, so that now the closest professional association of neurology is probably with neurosurgery rather than psychiatry.

Pediatrics and pediatric surgery worked very closely together for many years, but as the pediatric surgeon has increasingly developed his own methods of pre- and postoperative care, the pediatrician, while an intimate colleague, is not always involved.

Cardiology and cardiac surgery should ideally be very close in their clinical relationships. Surprisingly, there have been historical examples where cardiac surgery became very prominent in a hospital despite a general lack of interest and collaboration from medicine; fortunately, this has been the exception.

Radiology and radiotherapy present no analogy, since they were always uneasy bedfellows at best, perhaps more siblings than collaborators, now going their separate ways and usually dealing with entirely different patient populations.

The relation of anesthesiology to surgery is, there-

TABLE 1. Manpower Estimates—Anesthesia and Surgery

Line	Cohort and Year	Reference Data
1	American Society of Anesthesiologists (ASA)	
	December 1973	12,807
	December 1974	13,450
	December 1975	14,210
	December 1976 (est.)	(Total) 15,300* 10,033 (active)
2	Residents in anesthesiology	
	Year end 1970	1,408
	Year end 1971	1,619
	Year end 1972	1,618
	Year end 1973	1,820
	Year end 1974	1,799
	Year end 1975	1,870
	Year end 1976	1,950†
3	American Association of Nurse Anesthetists	
	December 1973	(Active) 13,032
	December 1974	(Active) 13,918
	December 1975	(Active) 14,357
	December 1976	(Total) 17,364 14,800 (active)
4	Total anesthesia personnel (TAP)	
	December 1976 (est.)	32,050
5	Board-certified surgeons (BCS)	
	November 1971	46,469
	December 1975	54,996
	December 1976 (est.)	57,000
6	Surgical residents (RES) (advanced)	
	December 1970	12,565
	December 1971	13,697
	December 1972	14,102
	December 1973	14,555
	December 1974	14,772
	December 1976	15,100
7	Total surgeons (BCS + RES)	
	Year end 1976 (est.)	72,100

* This figure for total ASA membership includes some categories other than active licensed practitioners, as follows: in advanced residency (2,300), affiliated membership in Canada, foreign countries or in research (1,190), retired (536). The corrected figure for active practitioner members of the ASA is shown in the regional tables and is approximately 10,033.

† This residency listing overlaps with some residents who hold fellowship in the ASA. The estimated figure for total residents in Anesthesiology as of year end 1976 is 2,400.

fore, unique. While this has educational significance, its most important impact lies in public service, in the manpower ratios and ideal doctor mix involved between the two professions.

This relationship is also critical in any evaluation of the workloads and national scopes of the two professions. Whatever developments mandate more surgery also necessitate more anesthetics given. A pioneer student of this topic in surgery, Dr. John P. Bunker, is quite appropriately himself an anesthesiologist. In 1970, he published an article comparing the United States with the United Kingdom.[17] This was to stimulate a closer consideration of national surgical manpower and workloads. In that paper, Dr. Bunker took the view that the larger number of surgeons per unit population in the United States was responsible for the larger number of surgical operations. Possibly it is unfortunate that he did not give sufficient weight to the facts that there were more physicians of all types in the United States than in Great Britian (at that time approximately 145 active physicians per 100,000 population versus 100 per 100,000 population in the UK) and that all medical services were given in much greater profusion in the United States. As any visitor to British hospitals will testify, this applies equally to coronary care units, well-baby clinics, psychoanalysis, and radiologic examinations. Surgery and anesthesia were, therefore, just one part of a societal or cultural super-utilization of medical services in the United States.

My own involvement in this field began in 1969, with the undertaking by the American Surgical Association and the American College of Surgeons of a National Surgical Study (SOSSUS) that published its summary report in 1975,[18] and whose detailed documentary publication appeared early this year (February 1977).[19]

It is from this background that I would like to look at the national distribution of surgeons and anesthesiologists, and particularly to examine the problem of the ratio of the one to the other, and the impact on that ratio of active nurse anesthetists.

Manpower Data

In table 1 are shown manpower estimates for anesthesia and surgery. Wherever possible, these have been updated to December 1976 or January 1977.† The information about residents in anesthesiology is provided by publications of the ASA, as further checked in the AMA "Distribution of Physicians" for the years shown.[20] The term "total anesthesia personnel (TAP)" in table 1 refers to the sum total of American Society of Anesthesiologists membership plus their residents in training,‡ plus the active practicing

† The author is indebted to Mr. William Marinko, Associate Executive Secretary of the American Society of Anesthesiologists, for providing data and checking over tabulations; to Mrs. Josephine Heimler, Associate Director, The American Association of Nurse Anesthetists, likewise for providing data and checking tabulations in nurse anesthesia. The author is also indebted to Dr. Richard Kitz, Dr. Richmond Ament, and Dr. Leroy D. Vandam for reviewing some of the personnel tabulations and data. The opinions expressed and interpretations offered are those of the author.

‡ In the tabulations beyond table 1, trainees are omitted.

membership of the American Association of Nurse Anesthetists.

The data on Board-certified surgeons have been corrected for death and retirement, and updated by extrapolation of prior curves to year-end 1976. These are the best estimates currently available to the author. The data have been corrected for "double-boarding." That is, when a surgeon has registered as having two Board certifications he is nonetheless enumerated as a single individual. The information about surgical residents in advanced years of training is from the AMA "Distribution of Physicians" for year-end as shown.[20] These data have likewise been updated by curve extrapolation, providing an estimate for the year-end 1976 of 15,100 surgical residents in advanced years of training. By "advanced years of training" is meant individuals beyond first year after medical school, enrolled in surgical residency programs. The AMA, over recent years, has published two sets of data on numbers of residents. The mid-year listing in the "Directory of Approved Residents" is based on reports from Program Directors; the year-end data published in "Distribution of Physicians" regularly show a lower number, providing the basis for the data included here.

The term "total surgeons" refers to Board-certified surgeons plus their residents in advanced years of training. This takes note of the fact that residents in advanced years of training are responsible for carrying an important fraction of the national surgical workload. In table 1 no effort is made to enumerate the total number of persons who carry out surgical operations (including approximately 10,000 individuals in general practice, 10,000 noncredentialed surgeons, and approximately 10,000 internists, pediatricians or radiologists who carry out procedures in the operating room from time to time). The operations performed by the latter, including those done by internists (such as endoscopy) or radiologists (radium insertion), often require the administration of an anesthetic. To be all-inclusive, analysis of anesthesia workloads would require detailed local and regional records to determine what fraction of the total work of nurse anesthetists or anesthesiologists is concerned with this latter group of noncredentialed surgeons. As shown by the studies of Nickerson,[21] about 75–95 per cent of the surgical procedures in this country (corrected for magnitude of procedure) are carried out by Board-certified surgeons working with their residents in advanced years of training. In obstetrics, the figure is far lower; estimates suggest that in parts of the country more than 50 per cent of the obstetrical deliveries are carried out by non-Board-certified surgeons, obstetricians or gynecologists; it has been estimated that only 15 per cent of the obstetrical deliveries in this country are attended by physician anesthesiologists (personal communication, Dr. R. Ament).

The SOSSUS Report was completed in the autumn of 1974, and published in the summer of 1975. Based on data for year-end 1974, the total number of Board-certified surgeons plus their residents was estimated at 64,000–66,000. These data, updated two additional years to 1976, show 72,100 in the credentialed cohort of surgeons and their residents in advanced years of training. The ratio of Board-certified surgeons to population has increased approximately 4.5 per cent per year in the last four years.

The number of surgical residents has also increased, approximately 2,000 more residents being enrolled in non-federal programs in 1975 (year-end) than at year-end 1969. As shown in table 1, the membership of the ASA has also increased during this time, estimated to be an increase of about 6 per cent per year in the population ratio. In both instances "population ratio" refers to the ratio of persons enumerated to the total population they serve. This is most readily expressed as number of physicians per 100,000 population.

The data for nurse anesthetists as shown in table 1 may be criticized because they do not include nurses in training; opinions differ as to what extent nurse trainees provide an important component in the national workload of nurse anesthetists. The omission is probably not misleading in evaluating the total number of active working nurse anesthetists. Data regarding the number of nurses in the training schools are readily obtainable from the AANA.

Table 2 shows relationships between groups of surgeons and collaborating groups of anesthesia personnel, as derived from table 1. The data are self-explanatory. It is evident from tables 1 and 2 that the relative proportions of residents in relation to credentialed practitioners are about the same for surgery and anesthesiology. In surgical postgraduate programs the fraction of foreign medical graduates (FMG) is estimated to be approximately 18–22 per cent at the present time. In anesthesiology, numbers of FMG in residency training programs have ranged from 45 to 55 per cent of total enrolled residents.

In table 3 are shown regional data for the distribution of the membership of the American Society of Anesthesiologists. Population data are based on the 1970–75 curve updated to January 1977.

It is evident that the national distribution ratio for anesthesiologists (members of the ASA) is approximately 4.64 anesthesiologists per 100,000 population. As is the case with many other medical and surgical specialities, the distributional ratios are highest in the northeast and mid-Atlantic states and on the Pacific coast (5.5 to 6.9 per 100,000). The east north-central (middlewestern urban states) and the mountain states

TABLE 2. National Manpower Ratios—Anesthesia and Surgery—Based on Best Estimates for December 1976 (Table 1)

Line	Ratio	Ref Table 1	Abbrev.	Table 1 (Abs.)	Ratio
1	Board-certified surgeons and residents to total anesthesia personnel	Line 7 / Line 4	BCS + SR / TAP	72,100 / 32,050	2.25
2	Board-certified surgeons to American Society of Anesthesiologists (active)	Line 5 / Line 1	BCS / ASA	57,000 / 10,000*	5.70
3	Surgical residents to anesthesia residents	Line 6 / Line 2	SR / AR	15,100 / 2,400	6.29
4	American Society of Anesthesiologists to American Association of Nurse Anesthetists	Line 1 / Line 3	ASA / AANA	10,000 / 14,800	0.67
5	Board-certified surgeons plus residents to American Society of Anesthesiologists and residents	Line 7 / Lines 1 & 2	BCS + R / ASA + R	72,100 / 17,250	4.17

* This figure for total ASA membership includes some categories other than active licensed practitioners, as follows: in advanced residency (2,300), affiliated membership in Canada, foreign countries or in research (1,190), retired (536). The corrected figure for active practitioner members of the ASA is shown in the regional tables and is approximately 10,000.

occupy an intermediate position, around 4.5 per 100,000. The south Atlantic, east south-central, west south-central and west north-central areas have the lowest distributional ratios (3.0 to 3.9 per 100,000).

In table 4 are shown the regional distribution of nurse anesthetists and some estimates of total anesthesia personnel (TAP). The latter figure for total anesthesia personnel is the sum of ASA members plus nurse anesthetists, omitting residents (for whom we do not have regional distributional data). Population figures are the same as those in table 3.

TABLE 3. American Society of Anesthesiologists, January 1977 Regional Estimates

Region	Active	Population ($\times 10^6$)	Ratio Active per 100,000 Population
Northeast	844	12.3	6.86
Mid-Atlantic	2,051	37.3	5.49
S. Atlantic	1,348	34.7	3.88
E. S. central	408	13.7	2.98
E. N. central	1,865	41.0	4.55
W. S. central	760	21.4	3.55
W. N. central	596	16.7	3.57
Mountain	479	10.0	4.79
Pacific	1,682	29.0	5.80
TOTAL	10,033	216.1	4.64

TABLE 4. American Association of Nurse Anesthetists and Total Anesthesia Personnel, January 1977, Regional

Region	Active	Population ($\times 10^6$)	Ratio Active per 100,000 Population	TAP*	TAP/Population
Northeast	750	12.3	6.09	1,594	12.95
Mid-Atlantic	2,359	37.3	6.32	4,410	11.82
S. Atlantic	2,633	34.7	7.59	3,971	11.44
E. S. central	1,127	13.7	8.22	1,535	11.20
E. N. central	2,400	41.0	5.85	4,265	10.40
W. S. central	1,763	21.4	8.23	2,523	11.78
W. N. central	1,807	16.7	10.8	2,403	14.38
Mountain	594	10.0	5.94	1,173	11.73
Pacific	1,222	29.0	4.21	2,904	10.01
TOTAL	14,655	216.1	7.02	25,138	11.74

* TAP (total anesthesia personnel) refers to anesthesiologists plus nurse anesthetists, omitting trainees in both categories, and based on active United States members of ASA only.

The national mean population ratio for active anesthesia nurses is 7.02 per 100,000, while the highest distributional patterns of nurse anesthetists relative to population are to be found in the west north-central, east south-central and south Atlantic areas (8–10 per 100,000). These are precisely the areas that have the thinnest distributions of membership of the ASA. As shown in figure 1, the two distribution curves demonstrate a reciprocal relationship. This is most clear-cut in the west north-central area of the country, where the AANA distribution is at its highest (approaching 10 nurse anesthetists per 100,000 population) and the ASA membership is in its lowest range (3.6 anesthesiologists per 100,000 population).

The ratio of total anesthesia personnel (referring again to ASA plus AANA but excluding residents) to the population is shown in the right-hand column of table 4. It is almost constant throughout the country. The two exceptions, departing from a general level of 10.5–11.8 total anesthesia personnel per 100,000 population, are the west north-central and northeast areas, in which the ratios are quite high because of the abundance of nurse anesthetists. In general, where nurse anesthetists predominate in an area the total anesthesia personnel ratios are the highest.

The regional data in tables 3, 4 and 5 do not include trainees; the inclusion of trainees would not be expected to alter the configuration of the distribution curves, because in both anesthesiology and nurse anesthesia, the trainees are most abundantly distributed

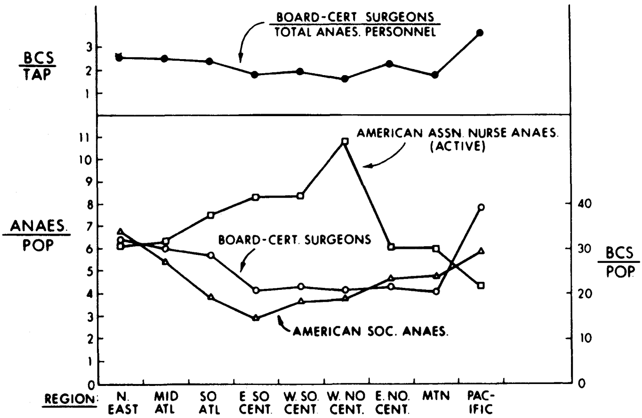


FIG. 1. Regional data for anesthesiologists, nurse anesthetists, and Board-certified surgeons (BCS), and ratio of total anesthesia personnel (TAP) to population. It is evident that anesthesiologists and Board-certified surgeons are relatively less numerous in certain areas of the country, generally in the rural midwest and southeast. In these areas, nurse anesthetists are more numerous. The resulting curve for total anesthesia personnel, and the relations of this group both to surgeons and to population, are rather constant throughout the country.

where there is the greatest concentration of qualified practitioners and teachers.

In table 5 are shown some estimates for regional ratios of Board-certified surgeons to total anesthesia personnel. As shown in table 2 the national average for Board-certified surgeons plus residents in training to total anesthesia personnel was 2.25 to 1. It is evident that this ratio becomes higher in the northeast and Pacific areas and lower in the west north-central, east south-central and mountain states. Considering the large variations in populations and in the locations of large metropolitan centers, and heavy industry, as well as the several categories of personnel concerned, it is remarkable that the variation around the mean of 2.25 is not very great.

Responsibility for the administration of anesthetics in the United States is currently being shared in a way that shows marked regional differences in the relative proportions of physicians to nurse anesthetists; at the same time, the United States has achieved a remarkable uniformity in distribution of total anesthesia personnel in relation to both surgeons and population (fig 2).

There is an analogy here to the distribution of surgeons themselves as displayed in the SOSSUS Report: while there does seem to be some regional inequity, it is ironed out to some extent when the distribution of surgeons is related to the distribution of available hospital beds.

By the same token, the wide availability of service facilities and the need for collaboration among surgeons, anesthesiologists, and the total personnel of each hospital have produced a rather even national distribution (fig. 2). Inequities are more directly related to regional availability of health care facilities than to any other single factor. These facilities are at their lowest distribution in the south Atlantic and east south-central areas. It is this factor—lack of facilities—that is responsible for what often manifests as a major inequity in personnel distribution. If the patients are there and hospitals present and equipped to care for them, then surgeons will enter practice and anesthesiologists with them.

Sex differences within the anesthesia personnel are notable. Most of the members of the ASA are men. Most of the members of the AANA have been women.§ Any analysis of the provision of anesthesia services must take into account this disparate sex distribution.

It appears to the intuitive judgment of many per-

§ Recent reports suggest that as of early 1977, as many as 23 per cent of active practicing nurse anesthetists were men (personal communication from Mrs. Heimler).

TABLE 5. Regional Ratios: Board-certified Surgeons (BCS) and Total Anesthesia Personnel (TAP)

Region	BCS/Population	TAP/Population	BCS/TAP
Northeast	33.5	12.95	2.59
Mid-Atlantic	30.3	11.82	2.56
S. Atlantic	27.5	11.44	2.40
E. S. central	20.6	11.20	1.83
E. N. central	22.0	10.40	2.11
W. S. central	23.1	11.78	1.96
W. N. central	21.7	14.38	1.51
Mountain	20.2	11.73	1.72
Pacific	36.7	10.01	3.67
Mean	26.2	11.74	2.26

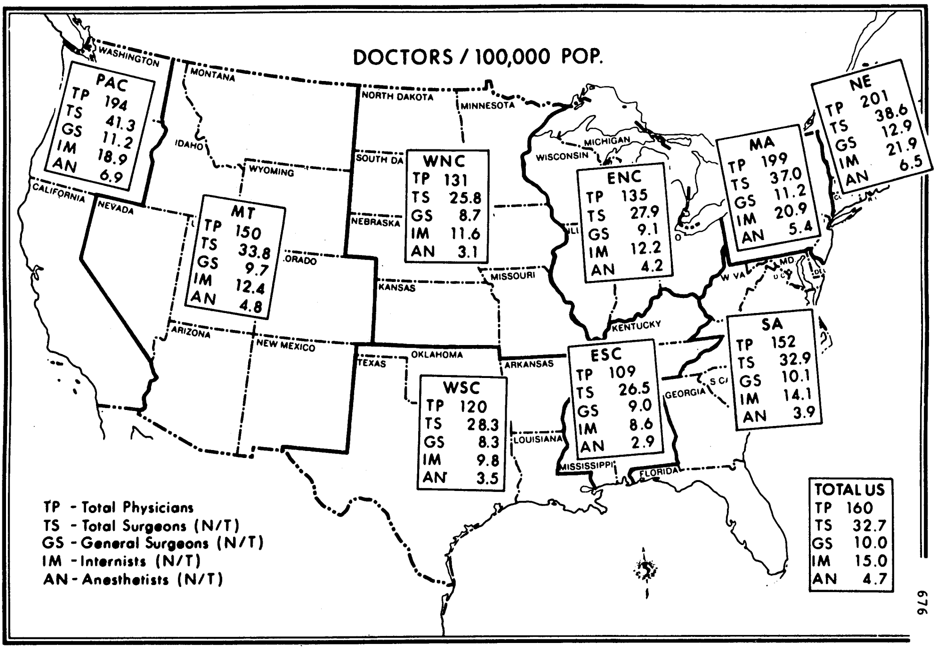


FIG. 2. Physicians per 100,000 population (adapted from SOSSUS Long Form Report[19] with permission of the Editor). Figures are shown for total physicians, total surgeons, general surgeons, internists, and anesthesiologists per 100,000 population for the nine major census districts. In the right lower corner are the totals for the United States. The abbreviation N/T signifies "not in training." The figure for anesthesiologists is based on the American Society for Anesthesiologists' data for 1972–73. Distributional aspects are described in the text.

sons concerned with this field that future recruitment policy will gradually, over the coming decades, even out some of the inequities by attracting more men into nurse anesthesia and more women into anesthesiology.

In table 6 are shown estimates for the numbers of anesthetics administered by nurses and by physicians according to numbers of hospital beds and according to year by recent decade.[11] These data are helpful in understanding the relative preponderance of nurse anesthetists in certain areas of the country that are predominately rural and agricultural, even though large cities with medical centers are also included. In rural areas small hospitals predominate. In hospitals that have fewer than 100 beds approximately 65 per cent of all anesthetics are given by nurses. In the larger hospitals this figure decreases to about 42 per cent and physician-administered anesthesia becomes predominant (fig. 4). In the large metropolitan areas of the northeast, and the Pacific coast and the east north-central areas of the country, physician-administered anesthesia predominates. There is also a relation here to the average size of hospitals, which is larger in the metropolitan area.

Manpower Contrasts and International Comparisons

Should an effort be made to effect a large increase in the number of anesthesiologists or nurse anesthetists in this country? There certainly are no data to suggest that any portion of this country experiences a limitation in delivery of surgical services because of the limitation in availability of anesthesia personnel. Despite this national generalization, there are focal areas where one may discover by casual conversation or anecdote that surgeons express the desire to have more anesthesiologists available.

In conjunction with the SOSSUS questionnaire, it was possible to assess the opinions of surgeons about the relative abundances of other specialists.[22] The questionnaire returns (with the responses numbering about 5,700) showed that only 10 per cent of the respondents considered that there was a shortage of radiologists, whereas 77 per cent thought that the number of radiologists was about correct and 7 per cent considered that there was an excess; 6 per cent expressed no opinion.

The position with respect to anesthesiology was quite different. Of 5,730 respondents who addressed themselves to this question, 41 per cent believed that there was a shortage of anesthesiologists in their area, whereas only 51 per cent believed that it was "about right." Only 3 per cent experienced an excess, 4 per cent having no opinion. This position with respect to anesthesiology, makes a contrast not only with radiology, as mentioned above, but also with pathology. With respect to pathology, 5,697 respondents addressed the question of abundance; 11 per cent indicated a shortage of pathologists, 77 per cent experiencing a distribution that was "about right," 4 per cent an excess, and 9 per cent no opinion.

From this brief excerpt of information from an article to which the reader is referred for details,[22] it is evident that almost half the surgeons responding felt that there was a relative shortage of anesthesiologists. Although this cannot in any sense be considered a universal or final consensus, the sample was large and carefully selected and stratified by strict statistical techniques. It did indeed show that more surgeons perceive a shortage of anesthesia services than perceive shortages in the hospital-related fields of radiology and pathology.

In this regard, it might be helpful to compare figures for the United States with those for other countries. For detailed data, not presented here in the interest of brevity, the reader is referred to Volume I of the "Long Form Report" of the Surgical Services Study (SOSSUS),[19] where international comparisons of physician manpower shown by tabulation and charts are presented (page 759 *et seq.*). In figure 3 is shown an abstract of some of these data, presented graphically.

TABLE 6. Anesthesia Services by Hospital Size and Decade

	Beds				Years		
	0–49	50–99	100–249	250+	1955	1965	1971
Anesthesiologists (per cent)	11	16.6	35	47.5	18	39	38.3
Nurses (AANA) (per cent)	67	65	50.4	42.6	34	45	48.5
Other physicians (per cent)	16	14	11	7.3	27	11	9.7
Other nurses (per cent)	5	4	3	2	19	3	2.8
Miscellaneous or other (per cent)	0.6	0.5	0.6	0.7	2	1	0.6

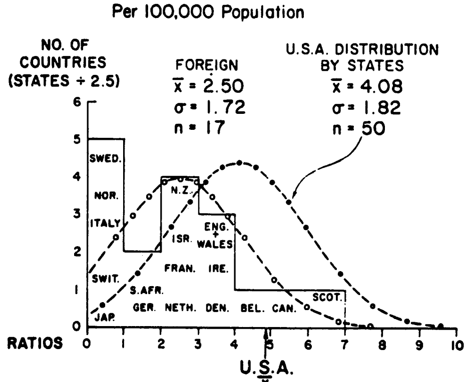


FIG. 3. Frequency distribution curve for anesthesiologists in foreign countries compared with the United States (adapted from SOSSUS Long Form Report[19] with permission of the Editor).

It is evident that certain of the western European or English-speaking countries (Scotland, Canada, England, Wales, New Zealand, Belgium, Denmark, Netherlands, France, Ireland, and Israel) enumerate anesthesiologists much as do the United States manpower data. That is, they enumerate them as physicians, showing distributional data of 2.5 to 6.5 anesthesiologists per 100,000 population. Although this is a wide range, it is evident from figure 3 that the mean is about 4 anesthesiologists per 100,000 population. In both instances the standard deviations are large, there is much overlap between the United States and some foreign countries, and the differences cannot be considered significant.

There is a second group of countries, including South Africa, Germany, and Spain, in which the enumeration is intermediate, showing slightly less than 2 physician anesthetists per 100,000 population.

Then there is a third group, including Sweden, Norway, Italy, Switzerland, and Japan, in which the figure is so low (less than 1 per 100,000 population) that one must assume that the manpower data base is entirely different or that most of the anesthesia episodes are administered by nurse anesthetists, not enumerated. From this evidence one would suggest that the proportion of anesthesiologists in this country is adequate as compared with other countries; when to that number is added the information about nurse anesthetists reported in this paper, it becomes evident that our total anesthesia personnel availability is as great as or greater than those of comparable countries.

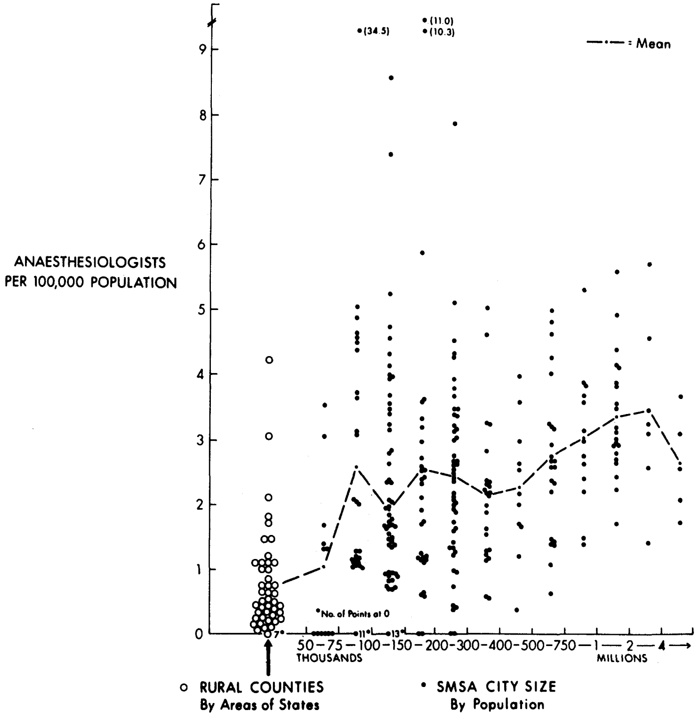


FIG. 4. Community-size distribution of Board-certified anesthesiologists, based on data from the 50 states. Left (*open circles*), data for rural counties, with the mean for each state. Right, populations of urban centers (SMSA), by increasing size. Each dot represents the population ratio for anesthesiologists in one city. The dotted line is drawn through the arithmetic mean for each group of cities in the population bracket. Anesthesiologists show a slight trend towards a more urban/metropolitan distribution. This trend is small, however, compared with the steeply rising slope for internists plotted in the same manner.[19] Surgeons show a slightly flatter slope, indicating a somewhat more even distribution in the smaller communities. The reader is referred to the SOSSUS Long Form Report[19] for similar charts of community-size distributions of various specialists. The data shown here have not previously been published.

Trends

Accreditation and Credentialing

The data from the recent decades show the gradual emergence of the anesthesiologist, from administering 18 per cent to administering almost 40 per cent of anesthesias. The fraction given by nurses accredited by AANA has likewise increased (table 6).¶ By contrast, anesthetic administrations by other physicians and other nurses without these qualifications and credentials have declined markedly. The trend to national credentialing for anesthesia services is thus becoming strong and incontrovertible. This is a national trend in all fields of medicine, and it is particularly important in surgery, wherein Board certification increasingly dominates the credential process for staff appointment.

¶ There is a possibility of double-listing here, some AANA cases listed as given by nurse anesthetists having been supervised by ASA physicians.

Such a trend in credentialing in both anesthesiology and surgery appears to the author to be not only socially desirable but historically inevitable. The public expects, and the professions will provide evidence of, training, achievement and meeting of standards by those who provide public services that are both important to health and hazardous when poorly carried out. These criteria apply to both anesthesia and surgery. It seems evident that in the future, hospitals will move towards increasing strictness of credentialing in both these fields. It is my own hope that this credentialing will continue to be carried out through the private sector rather than by the government. An overview of the problem of credentialing as well as the possible government harassment through the Federal Trade Commission has recently been presented.[23] Sociologists and legislators frequently ask for "proof" of superiority, which is difficult to acquire in a society where a credentialed group already predominates numerically and takes on most of the more difficult problems. As mentioned in the article referred to above,[23] methods of credentialing and standards of excellence should always be improved, rather than devoting extensive research to seeking direct statistical proof of the superior performance of credentialled people.

Predictors of the Population Ratio

When professional personnel must pass through a distinct qualification episode ("entry gate") before starting practice, a predictive method can be evolved to express their future number relative to the population. The event of Board certification or ASA membership qualification constitutes just such an entry gate, where counting can be very accurate. This accurate count in surgery is referred to as the "Board-certification rate," *i.e.*, the number of new persons Board certified per year. When this number is related to the age group distribution of the practitioners of the population, and the death and retirement rates, it is possible to make future projections as to the numbers of those persons who will be alive and in active practice over the next two or three decades. The Bureau of the Census supplies future population forecasts which, though they have been undergoing some downward modification in recent years, are the most reliable we have.

The mathematical model and computer application for converting Board-certification rates into predictions of physicians per population over coming decades are shown in detail in the Long Form Report of SOSSUS.[19] Because very few surgeons remain in practice beyond the fourth year without Board certification (providing they have progressed and graduated from an accredited residency), such predictions are reliable within the limits of population variables.**

Similar growth rates for other branches of the medical profession are currently under study. It appears that internal medicine, radiology, and pathology are all growing much more rapidly than they did in the previous 30 years, and the same is true of primary care medicine, however one wishes to define that entity.

Data for anesthesiology are much more difficult to derive or predict, because some members of the American Society of Anesthesiologists are not Board certified and remain so in fully accredited positions, but without Board certification. It would be my prediction that Board certification will become a stricter credentialing criterion for anesthesiology in the future, as previously mentioned. Data for the growth of the AANA cohort are reasonably secure because of firm data describing the number in training, and the rather fixed fraction of the activity/inactivity ratio reported by the AANA.[11]

Foreign Medical Graduates

Uncertainty on the anesthesiology side relates also to the large number of foreign medical graduates in training programs. The Health Manpower Assistance Act of 1976 could decrease participation of foreign medical graduates in clinical training programs drastically. Were this to occur, there would be a sudden decrease in the number of anesthesiologists entering practice in the United States over the next 20 years.

Such federal legislation is prone to modification either by outright amendment or by changes in federal regulations by which the law is administered. It would, therefore, be unwise to make firm predictions; better to emphasize the uncertainty as to the number of anesthesiologists entering practice with Board certification in the next 20 years.

** The number of highly trained surgical specialists entering practice without any intent of achieving Board certification is, in my opinion, low at this time and declining. Some disagree with this view. It appears that the statistical data currently at hand suggest that entry into major surgical responsibility is becoming increasingly confined to those with Board certification, and it is noteworthy that in the residency questionnaire of SOSSUS[18,19] more than 96 per cent of all residents responding, including those in municipal tax-supported hospitals as well as university hospitals, indicated that they intended to become Board certified after the completion of their residency.

Such predictions of population ratio (*i.e.*, the number of physicians per 100,000 population) cannot be regional because the populations of regions and the internal migration of physicians within this country are too unpredictable. The recent growth of population in the "sun-belt" southwestern states has been accompanied by an increase in the total number of surgeons, anesthesiologists and training facilities that would scarcely have been predicted 20 years ago. Population ratio forecasts that we have made are, therefore, national rather than regional.

On that basis, the growth of surgery and anesthesiology can be predicted within the confidence limits of Board-certification rates and the data on age-group distributions. Specifically, Board-certification rates for the ten surgical specialities have grown from 2,985 in 1968 to 3,478 in 1974, uncorrected for double-boarding. The double-boarding correction reduces the figure by 12–18 per cent, depending upon the number of individuals Board-certified in thoracic surgery in any given year; the data for 1975–76 show the same continued slope of modest increase, approximating 2 per cent per year. This is in sharp contrast to the growth of the Board-certification rate in anesthesiology, which has doubled since its 1968 figure of 311, to 608 in 1975; some of the imbalance in training rates between the two fields is evidently being rectified. It is notable that certain other fields, especially internal medicine and radiology, also show brisk growth rates at this time.

Despite the modest growth in surgical Board certification, it is evident that the surgical profession is still growing faster than the population. Based on year-end 1975, it appears that the cohort of Board-certified surgeons is growing at about 5 per cent per year, while the population grows at 0.5–0.62 per cent per year. As mentioned previously, the corrected growth rate for the ratio of Board-certified surgeons in practice to the population has been about 4.5 per cent per year since 1970.

The large number of foreign medical graduates in anesthesiology training program in this country reflects the tendency of United States medical graduates (USMG) to enter other fields. The increasingly large number of women entering medicine in this country deserves a comment in this connection, and increasing class size suggests the possibility that more USMG's will enter anesthesiology.

Women in Anesthesiology; Men in Nurse Anesthesia

At the present time many medical schools in the country are enrolling as many as 33 per cent women in the first year. The national average currently is estimated to be 20 per cent. The question, therefore, arises as to what fields women will select for their careers in medicine as they become available in American medicine in large numbers for the first time. The record is so brief as to make analyses unreliable. It seems evident that more women will enter surgery in this country than has been the case in Great Britian, where many women have graduated from medical school over the past 35 or 40 years.

At the same time, there are certain fields that are well adapted for women in medicine because they do not involve prolonged commitment to individual patient care. This aspect makes it a little easier for the young mother to drop out of clinical practice for a few years, if needed, during childbearing and infant upbringing. Anesthesiology is one of those fields, along with pathology, radiology, rehabilitation medicine, research of all types, and positions in postgraduate teaching.

The perception of sex—femininity or masculinity—as having any particular features adapted to one profession as opposed to another is unfashionable at this time, and is often viewed with a sense of criticism or sex chauvinism by certain activist groups. Despite the desire to avoid discussion of the matter, the fact remains that some fields of professional work in medicine are well adapted to the needs of the woman practitioner to raise a family and enjoy the privileges of motherhood. As already mentioned, the large number of women in nurse anesthesia is a historical circumstance relating to the fact that most nurses in the United States have been women over the past century. Nonetheless, their activity in nurse anesthesia demonstrates clearly that some features of the career in anesthesia services are well adapted to the life-style of women. It would therefore seem so obvious as to be scarcely worthy of argument that improved recruitment of women into anesthesiology, and men into nurse anesthesia, would help to improve the balance and career opportunities for both sexes in both aspects of this important professional service.

The Physician's Assistant or Allied Health Personnel in Anesthesia

The current trend to evolve a new professional group—the physician's assistant in anesthesia—often recruiting large numbers of men into training programs, seems in part to be a response to the preponderance of women in nurse anesthesia, and, for some male enrollees, the greater attractiveness of a predominantly male cohort. The physician's assistant is perceived as an individual who has learned the administration of anesthetics at the technician level, but somehow works in a manner distinct from nurse anesthesia. Men have predominated in the technical fields of inhalation therapy and respiratory management. This provides another track or professional activity for men, many of whom have completed a college education. Some have been unable to achieve admission to medical school. The respiratory therapist as a member of the health team, without the M.D. degree, has thus become an established and effective feature of many of the larger hospitals and urban centers. In many hospitals this service is directed by the Chief of Anesthesia.

In anesthesiology itself, the definition of "physician's assistant" or "allied health personnel" has not been agreed upon. Historically, the nurse anesthetist has always appeared to represent the very prototype of the relation between physician and assistant: a highly trained, technically expert person who has worked in close collaboration with the anesthesiologist. It seems self-evident that it is to the advantage of all aspects of anesthesia care in this country to avoid a further subdivision of non-physician anesthetists according to sex, or according to new training programs, or based on the presence or absence of a nursing diploma or degree. The nurse anesthetist has ideally functioned as a physician's assistant.

In my opinion there is nothing to gain by the growth and designation of a new third or fourth cohort of credentialed individuals to work with anesthesiologists. It would seem preferable to strengthen the current relationship, whereby the status of AANA membership is clearly recognized and members of the AANA carry approximately 50 per cent of the workload of American anesthesia services. Jurisdictional division or political pressures to modify or divide this group would not seem to be in the public interest or to lead to improved patient care.

This matter is of great moment and deserves wide discussion now, because new federal regulations, drawn up as part of new legislation, could threaten the status of the nurse anesthetist through the granting of some sort of privilege or categorical identification to a group of physician assistants in anesthesia who would receive an alternative training program and who would not be a part of the AANA activity. The political process in the United States is particularly sensitive to strong lobbying pressure from new splinter groups of old professions or from dissatisfied minorities who perceive themselves as being excluded from established groups.

The role of the physician's assistant in surgery is still not clear; to many observers of the subject there appears to be waning enthusiasm for that personnel category, and a general sense of failure to define a wide national role, even though certain specific categories (emergency ward assistants, orthopedic assistants) may prove to be viable and enduring career patterns.

By sharp contrast, the role of the nurse anesthetist has not been in question; it has been neither insecure nor indefinable. It has grown in strength and scope; many schools of nurse anesthesia have recently been strengthened or enlarged.

In summary, then, trends in anesthesia suggest an increased emphasis on accreditation and credentialing both in anesthesiology and in nurse anesthesia, a gradual levelling out of the disparity of sex roles, a possible decline in anesthesiology trainees with forthcoming limitation in FMG, and the growing importance of maintaining and strengthening the cohort of nurse anesthetists as the prototype "physician's assistant" in anesthesia without dividing this group by new jurisdictional disputes or accreditation definitions.

The large increase in USMG during the past decades will produce a "wave" of increased numbers of postgraduate trainees (interns and residents) in all fields over the next ten years. The decrease in anesthesiology trainees threatened by federal intervention in FMG immigration may be modified by the greatly increased number of USMG entering several fields; recent Board-certification trends in anesthesiology provide a base for expectation that more USMG will enter anesthesiology in the next decade.

Summary and Conclusions

1. Anesthesiology and surgery constitute two of the most closely interrelated branches of the medical profession. The manpower relationships between the two are, therefore, important both in the delivery of professional services in the United States, and in any manpower planning that may be undertaken.

2. The manpower data in this article arise from many sources. We are indebted to the American Society of Anesthesiologists and the American Association of Nurse Anesthetists for information updated to late 1976 or 1977. Standardization of terminology and increased accuracy of manpower reporting in all aspects of the health professions are objectives sought by all workers in this field.

3. The ratio of Board-certified surgeons plus their residents in advanced years of training to total anesthesia personnel is approximately 2.25 to 1, nationwide. The ratio of Board-certified surgeons in practice to active fellows of the American Society of Anesthesiologists is about 5.7 to 1. Data suggest that the growth of anesthesiology is proceeding at a more rapid rate than is that of the total of Board-certified surgeons. Recent trends in Board-certification rates in the two fields corroborate this; Board certification in surgery is growing at about 2 per cent per year, while in anesthesiology the figure has almost doubled over the last eight years.

4. The active ASA membership shows a population ratio of about 4.6 per 100,000 population, the active membership of the American Association of Nurse Anesthetists, about 7.0 per 100,000 population. Nationally, the total of anesthesia personnel of both categories (omitting trainees) is about 11 per 100,000 population. A comparable figure for Board-certified surgeons is about 26–28 per 100,000.

5. Anesthesiologists are most numerous in the northeastern, northwestern, and eastern midwest parts of the country. Nurse anesthetists are more common in other parts of the country, especially in the west north-central district. By this distributional circumstance, an equity has been achieved whereby the ratio of total anesthesia personnel to population is quite constant across regions of the country, as is the numerical ratio of total anesthesia personnel to Board-certified surgeons.

6. Anesthesiologists are more numerous and give a larger proportion of anesthesia in the larger hospitals and in larger cities, whereas nurse anesthetists predominate in smaller hospitals and more rural areas.

7. Comparison with foreign countries shows that the United States figure for anesthesiologists is in the same range as but slightly higher than those for comparable countries.

8. There is a recent trend towards increased formality of credentialing in both anesthesiology and nurse anesthesia, with a marked diminution over recent decades in the total number of anesthesia administered by other persons.

9. There are more foreign medical graduates in anesthesiology training in the United States than there

are in surgical training, relative to total trainees. The impact of the Health Manpower Assistance Act of 1976 could be severe in terms of decreases in anesthesiology trainees and a sharp decline in the number of anesthesiologists entering practice, over the next decade.

10. Most anesthesiologists are men, a historic circumstance relating to the high proportion of men graduating from American medical schools. Most nurse anesthetists are women, likewise a historical circumstance relating to the history of nursing in this country. It appears evident that anesthesiology is one of the fields of activity that is well adapted to the special needs of women in medicine; a desirable trend —which appears to be on its way to realization— would be for a larger number of women in anesthesiology and a larger number of men in nurse anesthesia.

11. The recent trend to establish training schools and paraprofessional groups identified as "physician's assistants" or "allied health personnel" could have an adverse impact on the present equilibrium in American anesthesia services. It would appear desirable to stabilize the present relationship between anesthesiologist and nurse anesthetist, rather than challenging this long-standing relation by the establishment of new professional categories that will generate jurisdictional disputes among groups of nonphysician anesthetists.

The assistance of the Josiah Macy Jr. Foundation and that of the Henry J. Kaiser Family Foundation are gratefully acknowledged.

References

1. Rovenstine EA: The economics of the anesthesia service in a large municipal hospital. Anesth Analg (Cleve) 19:145–149, 1940
2. Rovenstine EA, Waters RM, Stiles AA, et al: Cyclopropane as an anesthetic agent: Preliminary clinical report. Anesth Analg (Cleve) 13:56–60, 1934
3. Rovenstine EA, Wertheim HM: Cervical plexus block. NY State J Med 39:1311–1315, 1939
4. Papper EM: Regional anesthesia: A critical assessment of its place in therapeutics. E. A. Rovenstine Memorial Lecture. ANESTHESIOLOGY 28:1074–1084, 1968
5. Beecher HK: Ethics and clinical research. N Engl J Med 274: 1354–1364, 1966
6. Vandam LD: Early American anesthetists: The origins of professionalism in anesthesia. ANESTHESIOLOGY 38:264–274, 1973
7. Rovenstine EA: Abstract of an Address of Retiring President. American Society of Anesthesiologists, Inc. ANESTHESIOLOGY 6:196, 1944
8. Ament R: ASA Committee reports on anesthesia manpower. ASA Newsletter 36:1, 1972
9. Carron H: Anesthesia manpower in the United States, Public Health Aspects of Critical Care Medicine and Anesthesiology. Edited by Safar P. Philadelphia, F. A. Davis, 1974, pp 245–264
10. Ament R: Demographic study of nurse anesthetists, 1972. Bureau of Health Manpower Project Grant NIH 72-4269 (P). Chicago, American Society of Anesthesiologists, 1972
11. Biggens DE, Bakutis A, Nelson VG, et al: Survey of anesthesia services. J Am Assoc Nurse Anesthetists 39:371–379, 1971
12. Kitz RJ: The practice of anaesthesiology in the U.S.A.: 1980, Anaesthesiology. Proceedings of the Fifth World Congress of Anaesthesiologists, 1972. Amsterdam, Excerpta Medica, 1973, pp 412–419
13. Orkin FK: Analysis of the geographical distribution of anesthesia manpower in the United States. ANESTHESIOLOGY 45: 592–603, 1976
14. Ament R, Kitz RJ: The 1974 ASA membership survey: Analysis of the professional activities and attitudes of active members of the American Society of Anesthesiologists. Anesthesiol Rev 3:12–19, 1976
15. Ament R: A demographic study of nurse anesthetist carried out by the American Society of Anesthesiologists with the cooperation of the American Association of Nurse Anesthetists. Bureau of Health Manpower Education, DHEW, Contract #72-4289. Progress Report
16. Feldstein PJ: The market for anesthesia services: Some estimates and recommendations. J Am Assoc Nurse Anesthetists 43:459–465, Dec 1975
17. Bunker JP: Surgical manpower: A comparison of operations and surgeons in the United States and in England and Wales. N Engl J Med 282:135–144, 1970
18. Study of Surgical Services for the United States. Published jointly, American Surgical Association and American College of Surgeons. Summary Volume, Aug 1975
19. Long form detail data report, Study on Surgical Services for the United States. American Surgical Association, Background Data, 3 volumes, Feb 1977
20. Haug JN, Roback GA, Martin BC: Distribution of Physicians in the United States, 1970. Chicago, American Medical Association, 1971
21. Nickerson RJ, Peterson OL: Doctors who perform operations: A study on in-hospital surgery in four diverse geographic areas. N Engl J Med 295:921–926, 1976
22. Bloom B, Hauck W, Peterson OL, et al: Surgeons in the United States: Opinions on current issues relative to surgical practice. Surgery (in press)
23. Moore FD: Manpower goals in American surgery: Implications for residency training, future surgical manpower in the framework of total United States physicians. Ann Surg 184: 125–144, 1976

-4-

A MEASURE OF WORTH

by E. S. Siker, M.D.

Anesthesiology
57:219–225, 1982

Reprinted from: ANESTHESIOLOGY, Vol. 57, No. 3, September 1982

E S Siker
3/24/83

The 1981 Rovenstine Lecture—A Measure of Worth

*E. S. Siker, M.D.**

I AM HONORED by this opportunity to present the 1981 Rovenstine address, the 20th in the lectureship established to commemorate the life of Emory A. Rovenstine, and to pay tribute to his contributions and to the vitality he imparted to a fledgling specialty.

Since this is the 20th Rovenstine Lecture and the first of this new decade, I felt that it would be appropriate to remind those of us who knew Emory Rovenstine, and to inform those who did not, about who he was. Dr. Rovenstine died more than 20 years ago, and because his influence occurred between 25 and 50 years ago, it should come as no surprise that today, the great majority of practicing anesthesiologists know little about him. Some will recall that he was principally responsible for the investigations of cyclopropane, contributed much to our knowledge of nerve blocks and the pharmacology of local anesthetic agents, and stressed the importance of good record keeping.

A second reason for spending more than the usual amount of time talking about Emory Rovenstine, is the title of this lecture—A Measure of Worth. How Emory Rovenstine measured his own worth and his positive views on the worth of anesthesiology serve as timely models in 1981, when so much of what we read and hear is negative and downbeat.

Emory Rovenstine was my Professor of Anesthesiology at New York University College of Medicine. He lectured to our class about the pharmacology of anesthetic agents, and also taught in the operating rooms. I was a third-year medical student assigned to a surgical clerkship on Bellevue's third division during the Fall of 1947. At the time, I did not call him Rovey, and he didn't call me anything at all. We did meet soon after that, and knowing him for only ten years, it was easy to understand why he was revered by so many.

A surgical colleague, quoted in a New Yorker profile about Emory Rovenstine, dated November 8, 1947, provided a more positive perspective of the man—and of the specialty—saying, "Being a Rovenstine anesthesiologist is being a good doctor. Those fellows know patients, clinical medicine and they know pharmacology. Dr. Rovenstine and his mentor, Dr. Waters, have made anesthesia grow up. It's no longer a branch of surgery, but a distinct branch of medicine and one of the most valuable. Nobody in the world knows more about physiology than a good anesthesiologist. They spend all of their lives finding out what makes people live."

I would like to spend time discussing such positive perspectives. Let me be more specific. The last four Rovenstine Lecturers are distinguished and respected colleagues, as well as friends. Their own individual contributions to our specialty are comparable in our times to those made by Emory Rovenstine in his time. Their dedication to the specialty can be assessed by the concerns that they expressed as Rovenstine Lecturers. In 1977, James Eckenhoff[1] discussed a number of these, including the quality of education of anesthesiologists, the malpractice dilemma, the interface between anesthesiologists and nurse anesthetists, and the progressive loss of support funds for research in anesthesiology. In 1978, William Hamilton† added his own concerns about the support base, as well as the relevance of current research in anesthesiology. Additionally, he reflected about the implications that could be drawn from the fact that over 80 per cent of residents in training chose the two-year practice option, rather than the specialized fourth year of the continuum of training, to satisfy the requirements for admission to the examination system of the American Board of Anesthesiology. In 1979, Roy Van Dam[2] administered a most scholarly spanking for our not infrequent failure to act as physicians, and to be seen by our patients as physicians rather than as a superspecialist who they sometimes don't even remember. In 1980, Jenkins‡ explained some worrisome complexities of medicine's societal fabric, and posed some related concerns that more specifically influence anesthesia practice. In addition, he painted a bleak portrait of potential State and Federal regulations that, if legislated, would have no bearing on quality care.

The concerns expressed by Drs. Eckenhoff, Hamilton, Van Dam, and Jenkins are well-founded, and I share

* Chairman, Department of Anesthesiology.

Received from the Department of Anesthesiology, Mercy Hospital, Pittsburgh, Pennsylvania. Accepted for publication March 29, 1982. Presented as the 1981 Rovenstine Lecture, October 19, 1981, New Orleans, Louisiana.

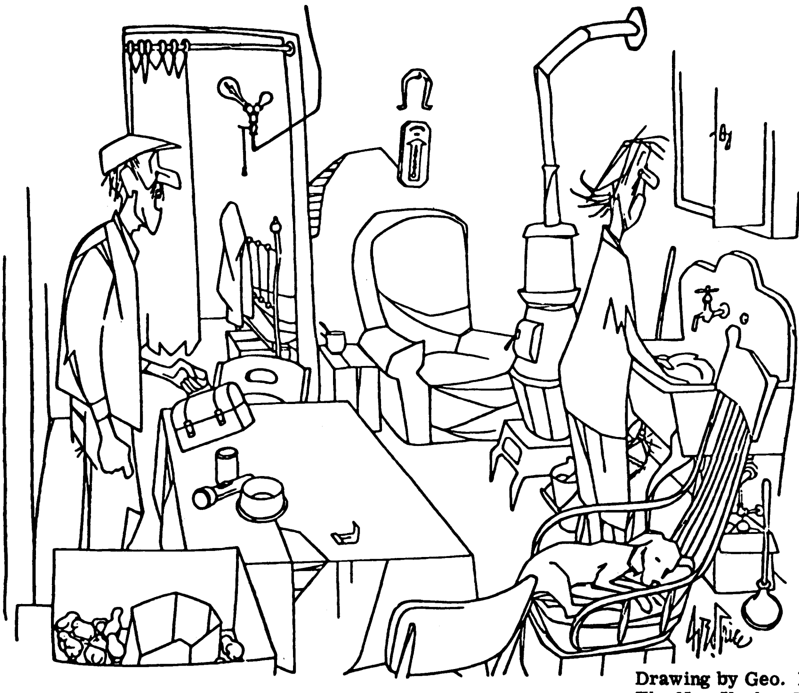
Address reprint requests to Dr. Siker: Department of Anesthesiology, Mercy Hospital, 1400 Locust Street, Pittsburgh, Pennsylvania 15219.

Key words: Anesthesiologists. Anesthesiology. Manpower. Organizations: ABA; ASA.

† Hamilton WK: Personal communication.

‡ Jenkins MT: Personal communication.

0003-3022/82/0900/0219 $01.15 © The American Society of Anesthesiologists, Inc.



Drawing by Geo. Price; ©1973
The New Yorker Magazine, Inc.

FIG. 1. "I heard a bit of good news today. We shall pass this way but once."

most of them since they could well be restated here and now. If, however, there were no balances for these concerns, if there were no quid pro quos, or no gratifications, a practitioner of anesthesiology might well identify with the man in the Price cartoon (fig. 1).

As I read what's been written and remember what's been said over the past 30 years, I find that we, as anesthesiologists, have excelled in self-criticism, but rarely have contributed in providing a more positive image of ourselves. Although the ASA has awarded journalism prizes to those members of the media who have contributed accurate and informative portrayals of our specialty, it was only during this past year that Dr. Eli Brown inaugurated the ASA Public Education Program. The first phase of this program has been completed, and consisted of a media tour, the filming and distribution of a five-part video news release, and the distribution of a film about anesthesiology. Dr. Brown and the program he inaugurated deserve our support, and our congratulations; it was long overdue. I believe that it is necessary not only to inform the public, but also to recognize the contributions of those within our ranks, and to acknowledge that they have earned a respected place for our discipline in the scientific community of American medicine.

As we consider the worth of our specialty and its practitioners, however, there continues to be an intrusive and disturbing undertone that suggests both anesthetic mismanagement and negligence as causes of peri-operative complications whenever no other obvious causes can be identified. A possible basis for such an underlying bias was posed in the December 1978 issue of *Anesthesiology.* In an editorial on anesthetic morbidity and mortality, Robert Epstein[3] wrote, "there is a natural abhorrence of any worsening of the condition of patients secondary to administration of anesthesia which after all offers them no direct benefit." Is there truly an unfair bias that indicts us without justification, or are we, as anesthesiologists, guilty of error and negligence to a degree that exceeds our counterparts in other disciplines? This question was, in part, the subject of a recent debate that relates to our perceptions of anesthesia practice.

An article by Arthur Keats[4] was entitled, "What Do We Know About Anesthetic Mortality?" In this article, Dr. Keats proposed that anesthetic management has been unfairly incriminated as a primary or contributory cause of death for more than 30 years, due, he claimed, to an error bias that was built into such studies as mortality reviews and anesthesia study commissions of this era. Dr. Keats carefully documented a major role that anesthesiologists played in creating this error bias, and wrote that medicine has not conferred on anesthetic agents the same risk/benefit scale enjoyed by all other forms of therapy. This same issue of *Anesthesiology* contains a rebuttal editorial by William Hamilton,[5] who disagreed that unanticipatible, unknown, or unpreventable adverse drug reactions play a significant role in anesthetic mortality. He suggested, instead, that human error is a more plausible and rational explanation, even in the absence of our ability to document it. The debating skills of Dr. Keats and Dr. Hamilton are well-known, and I would rather have them continue to argue with each other than with me. But since the issue bears upon our worthiness, some comments are in order.

The nature of anesthesia practice is such that exposure to risk is inordinately high. Additionally, more than in any other specialty, we work before an audience of our peers, without the sanctuary of the private offices where physicians in other specialties spend a significant amount of their time, and where little risk is involved. As we care for more gravely ill patients, the deck becomes more stacked. In his 1975 John Snow lecture, Derek Wylie[6] put it well when he said:

> "It is possible to make the wrong clinical decision for the best of reasons and have the patient die, and it is equally possible to carry out all the correct procedures and yet have an ill or difficult patient die—without in either instances being negligent."

While time continues to yield explanations for intra- and postoperative complications only indirectly related to the anesthetic, evidence of bias is not hard to find. A good case in point was the attitude of a famous forensic pathologist in the early 1950s. When he could find no obvious case of death in a patient who had succumbed during or shortly after an operation, the pathologist turned to the anesthetic record and after writing, "Cause of Death," merely copied the names of anesthetic agents used. With the passage of years, we, and hopefully our colleagues in other disciplines, have become more sanguine and recognize that there are many factors over which we have little control, but which do impact on the tolerance a patient may have for anesthetic agents. As an example, alcoholism and other forms of drug addiction carry an implicit risk which, while not absolving anesthetic practice, reduces blame if and when such patients have complications.

TABLE 1. Influence of Alterations of $PaCO_2$ on Neurologic Results of Carotid Endarterectomy[8]

	Hypocarbia	Normocarbia	Hypercarbia
Number of patients	42	16	42
Pa_{CO_2} (mmHg)	25	25–60	60
Postoperative neurologic deficit	2	0	3
Intraoperative arrhythmias (%)	12	25	45

Our understanding of factors influencing postoperative respiratory problems warrants comment. It wasn't too long ago that pneumonia following anesthesia was an accepted cause-and-effect relationship. While a relationship still probably exists, we are not terribly defensive about respiratory complications in a patient who is obese, or who is a heavy smoker, or both. We recognize the self-imposed risks that life-styles create for the patients entrusted to our care, and we do our best to minimize such risks. As time goes on, new studies continue to provide information about mechanisms that explain complications once attributed to some unknown but dire effect of the anesthetic process. In the recent past, well-known examples of such mechanisms include the genetic basis for malignant hyperpyrexia and atypical responses to succinylcholine. We have become more informed about the nutritional implications of anesthesia. For example, Garibaldi and Pace[7] reported in the March 1981 issue of the *American Journal of Medicine* that increasing ASA classifications numbers and decreasing serum albumin levels were significantly correlated with postoperative pneumonia, irrespective of such time-honored factors as age, sex, weight, smoking, COPD, or the site or duration of surgery. Such findings reduce the presumption of our involvement and permit the prediction that continued research will provide additional answers.

What about our colleagues on the other side of the screen? The assumption of a surgical etiology for postoperative neurological deficits has, until recently, almost been restricted to intracranial and open-heart procedures. Any other neurologic problem was, almost by definition, anesthesia-induced. Increasing evidence from our surgical colleagues suggest that we, as anesthesiologists, may have been premature in claiming or even accepting a share of the responsibility for such untoward outcomes. A notable example is the carotid endarterectomy. In the September–October 1976 issue of *Stroke*, Baker[8] and his associates reported that in a group of patients undergoing carotid endarterectomy (table 1), intraoperative hypercarbia significantly increased the in-

TABLE 2. Hypotension and Transient Ischemic Attacks[10]

	Number of Patients	Average Reduction of Blood Pressure
No focal signs	17	59%
Unrelated focal signs	7	
Focal signs after general ischemia	12	57%
TIA	1	
TOTAL	37	

cidence of intraoperative arrhythmia. There was, however, no significant relationship between the difference in the incidence of postoperative neurologic deficits and the occurrence of hypocarbia, normocarbia, or hypercarbia. Even more provocative, Prioleau[9] and his associates reported that in a comparable series of patients, the incidence of stroke was 9.5% in 137 patients in whom an intraluminal shunt was used, and less than 1% in 116 patients in whom a shunt was not used. It now seems obvious that when postoperative neurological deficits occur where shunts have been used, changes in Pa_{CO_2} deserve low priorities as possible causes.

A time-honored intra-operative complication is hypotension. The evidence, however, has long suggested that our collective willingness to blame almost any catastrophe on hypotensive episodes has not been documented. In fact, there are a number of studies that confound this assumption. As early as 1963, Kendell and Marshall[10] reported the results of a protocol in which hypotension was induced in 37 patients, with well-documented TIAs using intravenous hexamethonium and a tilt table. Systolic blood pressure was reduced to a mean value of 42% (table 2) of the initial pressure, or, mean reductions of 57 and 59% in patients who did and did not develop ischemic signs, respectively. In only one patient was a true, isolated transient ischemic attack reproduced; the remainder developed either unrelated focal signs or no evidence of focal cerebral ischemia until the effects of severe generalized ischemia developed. In 1971, Rollison[11] and his associates reported two groups of elderly men undergoing transuretheral resection under spinal anesthesia. One group did, and the other did not

TABLE 3. Cerebral Infarction and Hypotension[13]

Cerebral Atherosclerosis	N	Age	Fresh Infarct	Old Infarct
0	25	55	4	0
1	50	67	0	3
2	32	70	3	3
3	8	71	0	4
	135	65	7*	10†

* $P = 0.9$.
† $P < 0.05$.

receive prophylactic vasopressors to prevent hypotension. In the hypotensive group, the mean fall in blood pressure was 56%, compared with an 18% fall in the group treated with prophylactic vasopressors. There were no differences between the groups as measured by detailed postoperative psychometric testing. Again, these data suggest that our preoccupation with the sequelae of intraoperative hypotension, including potential neurological complications, may not be warranted. These studies in patients who seem to be prime candidates for hypotension-induced deficits, follow earlier studies by James Eckenhoff[12] who reported in 1964 that hypotensive anesthetic techniques did not cause changes in mental function in younger age groups.

In 1976, Torvick[13] asked the question, "How often are brain infarcts caused by hypotensive episodes?" Torvick reasoned that if hypotension is a major cause of brain infarcts, it would be expected that following an acute hypotensive episode, patients with severe cerebral atherosclerosis would have a high incidence of brain infarcts in addition to signs of diffuse cerebral hypoxia, while patients without cerebral atherosclerosis might only show signs of diffuse cerebral hypoxia. Torvick examined the brains of 135 patients who had been resuscitated after cardiac arrest with its obvious attendant, hypotension, and who subsequently died one day to several weeks after the episode. The specimens were graded 0 to 3 on the basis of the absence or the presence and degree of atherosclerosis (table 3). Only seven of these 135 patients had brain infarcts that were probably associated with the hypotensive episode during or after the resuscitation. Let me stress that I am not stating that hypotension is innocuous—nor am I unmindful of many well-controlled studies in which hypotension has been associated with serious sequelae. My concern is the unfounded generalization that when poor outcomes occur, the cause is anesthetic mismanagement whenever hypotension appears on the record, whatever the surrounding circumstances.

Let's return, briefly, to the procedure of carotid endarterectomy. Certainly, this surgical procedure is not intended to represent the broad spectrum of our anesthetic caseload. The data that we've just reviewed, however, suggest that intra-operative aberrations such as hypotension, hypocarbia, or hypercarbia, are not necessarily the cause of neurologic deficits when they occur. Data from the surgical literature suggest that surgical factors probably are the cause.

Let's look at another factor associated with postoperative problems. In the June 16, 1978 issue of the *Journal of the American Medical Association*, Steen, Tinker, and Tarhan[14] reported that of 587 patients who had suffered previous myocardial infarctions and underwent subsequent anesthesia and surgery, 36 (6.1%) re-in-

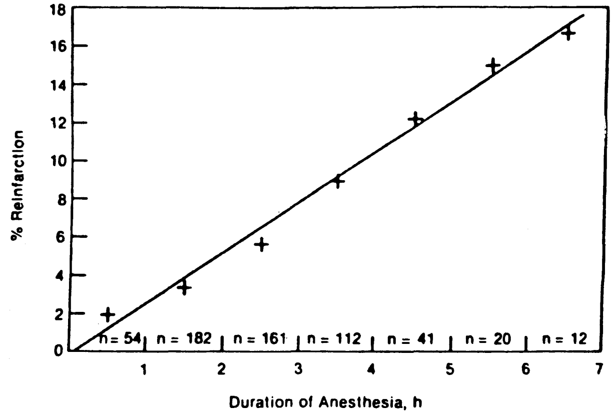


FIG. 2. Relation of myocardial reinfarction to duration of anesthesia.

farcted, and 25 of these patients died. A striking point made in this study dealt with the relationship between the re-infarction rate and the duration of anesthesia and surgery (fig. 2). The correlation is almost linear between the per cent of re-infarction and the duration of surgery for noncardiac thoracic and upper abdominal operations. Such operative sites were not a factor if the procedures were short. Whether the causes for this relationship are anesthesia or surgery, or both, the longer the operation requires the greater the risk in this group of patients.

The time has long since past when indications for surgery, the surgical procedure, surgical technique, and duration of surgery can be exempted from the same scrutiny accorded to anesthetic management.

Let's turn now to other yardsticks used by any specialty in measuring its worth. After returning from a two-week trip away from his department, Emory Rovenstine said to one of his associates, "Don't tell me the bad news, just tell me what you've gotten done while I've been away." Some of the best news is what the American Society of Anesthesiologists has accomplished and how its officers and members make it work for our collective benefit. We can be grateful for the leadership that our specialty has enjoyed, and for the methods that this Society has developed for channeling consensus into effective programs. The journal, ANESTHESIOLOGY, remains one of the most prestigious scientific journals in American medicine. The ever-expanding educational programs of ASA have responded to the requirements of its membership. One only need look at the total subscription of the annual refresher courses and their companion publications, as well as the continuing success of the regional refresher courses and the self-assessment examinations. What other major specialty in medicine speaks with a single voice? And it was with one voice that your specialty took on the Federal government over the issue of the relative value guide, and was judicially sustained for its efforts. Where ASA fought and was successful, radiology, pathology, orthopedic surgery, and obstetrics and gynecology all chose, rather, to sign consent decrees.

One area in which anesthesiologists have not only pioneered, but have made and continue to make fundamental contributions, is the discipline of critical care medicine. For many years, anesthesiologists held primary positions in this field by default—there were few others with the requisite training and skill. As it became more obvious that complicated care in tertiary settings would more and more depend, in an increasingly competitive marketplace, on the skills of the intensivist, the specialties of both medicine and surgery took note and vied for a more participative role. No longer does the anesthesiologist automatically inherit this area.

At the same time, many medical students and house officers in other disciplines, while not ultimately becoming intensivists, were recruited initially into our specialty by what they saw the anesthesiologist do in critical care units. In this context, then, I can report more good news—although this will be of interest to a significantly smaller segment of our specialty. Five years ago, the American Boards of Anesthesiology, Internal Medicine, Pediatrics, and Surgery agreed to explore the possibility of co-sponsoring a Certificate of Special Competence in Critical Care Medicine. Each of these Boards, and the Society of Critical Care Medicine, appointed one representative to begin the task. Our own representative in this effort was Dr. James Arens, Chairman of the Annual Session of 1981. On September 16th 1980, the new

TABLE 4. Number of Resident Positions filled by FMGs*
on September 1, 1973

Specialty	Total Positions Filled	Position Filled by FMGs	Per Cent
Anesthesiology	1,919	1,042	54
General surgery	6,373	1,990	31
Internal medicine	8,838	2,467	28
Obstetrics/Gynecology	2,884	940	33
Pathology	2,611	1,322	51
Pediatrics	3,973	1,204	30

JAMA: January 1975, volume 231, Educational supplement.
* Foreign Medical Graduate.

certificate was officially approved by the American Board of Medical Specialties, and in March 1981, the first organizational meeting of the ten-member Joint Committee was held in the offices of ABA which has been designated to administer the program. The work of approving applicant credentials and the construction of a certifying examination for those eligible for this new certificate has begun. While two years of special training in Critical Care Medicine are required for an internist, surgeon or pediatrician, only one year of special training in critical care is required of a physician certified in anesthesiology—appropriate recognition of what our specialty includes.

In listing the good things that we do, I hesitated to include the work of the American Board of Anesthesiology because I could rightly be accused of personal bias. But Emory Rovenstine was a founding Director of the American Board of Anesthesiology, and I believe that a brief report of its current status is in order.

Whenever the boards are mentioned, many conjur up images of inquisitional sessions, and while few really believe that this is how that body spends its time, equally few are aware of the many areas in which the Board works. Its principle responsibility is to certify. And, as of April 1981, the Board issued its 10,000th certificate. There is no uniformity between the different specialty boards. Each board sets its own standards for certification. The Board has spent most of its energies validating the process for primary certification, and as you are probably aware, not nearly as much of its energies are spent on the debated merits of recertification. In a formal response to our President, Dr. Eli Brown, the Board stated its position on recertification in the Spring of 1980 in the following words:

> Insufficient confidence in currently available methods of assessing competence of the practicing Anesthesiologist makes it inappropriate to implement a recertification process by 1984. While the American Board of Anesthesiology will continue to study all options for a meaningful recertification program, it will expend its major effort and resources toward improvements of the process leading to primary certification.

An additional role of the Board is that of a record keeper. As many of you know, it has been asserted that there is a disproportionately high number of foreign medical graduates in anesthesiology. Before I share some data with you, please understand that this is in no way intended to denegrate our colleagues who are foreign medical graduates, or their place either in medicine or in our specialty. The value of their scientific and clinical contributions speak for themselves.

By the same token, the increasing appeal of anesthesiology for American medical graduates can be viewed as a measure of how they view the worth of our specialty. If we look at these numbers[15] (table 4), we see that as of 1973, there were more than twice as many foreign medical graduates in residency positions in both internal medicine and general surgery than in anesthesiology. While the difference in percentages is impressive, actual numbers tell a different story. In table 5, we can examine the increase in the percentage of American medical graduates, and the increase in the total number of resident slots filled in anesthesiology over the past eight years, to an all time record as of July 31, 1981.

Most are familiar with the results of the Graduate Medical Education National Advisory Committee study, which projected a 15% shortfall by 1990. I believe that the projections are open to some questions. Two factors were not considered. Anesthesiology is no longer a young specialty. Our attrition rate, therefore, is comparable to any other specialty, which means that the large numbers who entered anesthesiology in the 1950s will, for all the various reasons, leave practice and require replacement. The second factor not considered is related to the absolute decrease in the number of foreign medical graduates entering the specialty. The 1976 amendments to the Immigration and Naturalization Act, Public Law 94-484, have deprived foreign national physicians of preferential immigration status and require that they pass the Visa Qualifying Examination (VQE) as well as the ECFMG examination. The pass rate on the VQE—given each September in most US Embassies—is approximately 25%. My concern, therefore, is that the shortfall will exceed the 15% projected by GMENAC. By 1985, I project that the total number of filled residency positions in anesthesiology will decrease to approximately 2,200, of which at least 80% will be American medical graduates. The bad news is that the shortage may exceed the one that many of us remember in the late 1950s and early 1960s. The downside risk of such a shortage includes the possibility that other options might be sought in solving the need for anesthesia personnel. The good news is obvious—a continued shortage should mean a continuing number of career opportunities in anesthesiology.

Finally, and appropriately, the dessert in this feast of accomplishments in anesthesiology is the progress that has been made in our ability to take care of our patients. Consider what has been made possible by the contri-

TABLE 5. Anesthesia Residents in Training (1973–1981)

	1973	1974	1975	1976	1977	1978	1979	1980	1981
PGY* 1	119	172	285	270	312	390	404	479	609
PGY 2	886	817	826	866	883	829	849	893	1,193
PGY 3	817	860	808	839	883	848	847	858	913
PGY 4	395	379	388	399	372	354	303	292	259
TOTAL	2,217†	2,228	2,307	2,374	2,450	2,421	2,403	2,522	2,974
Number of AMG‡	968	1,043	1,137	1,236	1,314	1,367	1,484	1,647	2,086
% AMG	43.7	46.8	49.3	52.1	53.6	56.5	61.7	65.3	70.14

* PGY = Postgraduate year.
† In Table 4, this number appears as 1,919, and represents a discrepancy between AMA statistics and those of the American Board of Anesthesiology, the source for table 5.
‡ American Medical Graduates.

butions of our colleagues in pediatric, obstetrical, neurosurgical, and cardiovascular anesthesia, and in critical care medicine and the treatment of chronic pain. Our ability to provide safe anesthesia for the ever-increasing number of elderly patients has literally changed the caseload of the daily operative schedule around the world.

Emory Rovenstine was a visionary, who viewed with great confidence, the future of anesthesiology. He would, I believe, have looked upon the achievements in anesthesiology over these past 25 years with an enormous feeling of pride and satisfaction—mostly because of our advances in caring for patients. He would view anesthesiology now, its scholarly contributions, its status in the family of specialties, its growth, its cohesiveness, and its strength as an organized specialty as vindications of his vision.

In this lecture, I've attempted to summarize the obvious: That anesthesiology is alive and well—and thriving. Those of us who are its practitioners have as much right to feel gratified with its progress as we are obligated to be concerned with its problems. However, to commemorate the life and contributions of Emory Rovenstine is to celebrate our specialty and its achievements. I have proposed that it is time to reexamine the myriad factors that surround perioperative complications, especially those in which there is a presumed anesthetic etiology. I have referred to the successes of the American Society of Anesthesiologists, the status and role of the specialty Board, and its participation in the development of a Certificate of Special Competence in Critical Care Medicine. The impressive number of prestigious and responsible positions held by anesthesiologists across the broad spectrum of American medicine, and in both elected and appointed governmental positions continues to increase. I have reviewed the growing popularity of our specialty, as evidenced by the absolute increase in the number of American graduates seeking careers in anesthesiology and, most important, the broad advances that have been made available to us in caring for our patients. While the real world in which we live will never be free of concerns, closing out this first year of a new decade seems an appropriate time to stop selling ourselves short and to embrace positive attitudes about ourselves and our future.

Let this then be the decade when we focus on our qualities rather than our flaws, our hopes rather than our concerns, our successes rather than our failures, and our dreams rather than our nightmares. Let it be a time to remember that the esteem of others will depend upon our own self-esteem, and that others will view us as no better than we view ourselves. Let us measure our worth as specialists in the practice of anesthesiology, so that as others measure our specialty, they will know its worth.

References

1. Eckenhoff JE: A wide-angle view of anesthesiology. ANESTHESIOLOGY 48:272–279, 1978
2. Vandam LD: American Society of Anesthesiologists Rovenstine Lecture—1979. ANESTHESIOLOGY 53:40–48, 1980
3. Epstein RM: Morbidity and mortality from anesthesia: a continuing problem. ANESTHESIOLOGY 49:388–389, 1978
4. Keats AS: What do we know about anesthetic mortality? ANESTHESIOLOGY 50:387–392, 1979
5. Hamilton WK: Unexpected deaths during anesthesia: wherein lies the cause? ANESTHESIOLOGY 50:381–383, 1979
6. Wylie WD: There, but for the grace of God. Ann R Coll Surg Engl 56:171–180, 1975
7. Garibaldi RA, Britt MR, Coleman MI, Reading JC, Pace NI: Risk factors for postoperative pneumonia. Am J Med 70:677–680, 1981
8. Baker WH, Rodman JA, Barnes RW, Hoyt JL: An evaluation of hypocarbia and hypercarbia during carotid endarterectomy. Stroke 7:451–454, 1976
9. Prioleau WH Jr, Aiken AF, Hairston P: Carotid endarterectomy: neurological complications as related to surgical techniques. Ann Surg 185:678–681, 1977
10. Kendell RE, Marshall J: Role of hypotension in the genesis of transient focal cerebral ischaemic attacks. Br Med J 2:344–348, 1963
11. Rollison WN, Robertson GS, Cordiner CM, Hall DJ: A comparison of mental function in relation to hypotensive and normotensive anaesthesia in the elderly. Br J Anaesth 43:561–565, 1971
12. Eckenhoff JE, Compton JR, Larson A, Davies RM: Assessment of cerebral effects of deliberate hypotension by psychologic measurements. Lancet 2:711–714, 1964
13. Torvick A, Skullerud K: How often are brain infarcts caused by hypotensive episodes? Stroke 7:255–257, 1976
14. Steen PA, Tinker JH, Tarhan S: Myocardial reinfarction after anesthesia and surgery. JAMA 239:2566–2570, 1978
15. Medical Education, JAMA (Suppl) 231:34–62, (Table p 40) 1975

-5-

ANESTHESIOLOGISTS COME OF AGE:
Their Stake in General Education, Research, Residency Education, and Selection of Medical Students and Faculty

by Eugene A. Stead, Jr., M.D.

SPECIAL ARTICLES

Anesthesiology
62:774–780, 1985

Anesthesiologists Come of Age

Their Stake in General Education, Research, Residency Education, and Selection of Medical Students and Faculty

*Eugene A. Stead, Jr., M.D.**

THIRTY YEARS AGO anesthesiologists were concerned with establishing their position in the world of medicine. Matters of the day preoccupied them, and they had little time to devote to the general problems of selection of medical students, role of research in medical school and residency programs, why medicine is a profession, and the differences between education and training.

Your place in the medical sun is now secure. You have the same needs for informed students, excellent research programs, and sophisticated faculty as do the older specialties of medicine and surgery. I am comfortable in appearing before you as a nontechnical expert to discuss with you the general nature of educational programs. I am pleased that three anesthesiologists whom I admire are in the audience. They are Ron Stephens, Manny Papper, and Jeep Pierce.

In my years as chairman of the Department of Medicine at Duke Medical School, I had the opportunity of interacting with a never-ending stream of bright young men. I interacted with them in their second year in medical school, teaching them some of the skills of a practitioner and, more importantly, a philosophic framework upon which they could arrange their future education and practice. I continued my efforts through their third and fourth years. I selected our interns in such a manner that 50% were Duke trained. I did this because I wanted our interns coming from other schools to come to a hospital that had a philosophic base and not to a place where only facts were presented. Our basis for selection was the desire to learn and work. We did not attempt to select persons who would do only internal medicine or research. I enjoyed our interns who headed toward surgery, anesthesiology, obstetrics and gynecology, ophthalmology, and ENT. In those days the surgical services at Virginia, Colorado, Kentucky, and Washington University did not require Duke medical interns to have a surgical internship. They came on service as junior residents.

Persons who went through the Duke Medical School and the Duke residency have characteristically said: "I can't remember any particular facts that Gene Stead taught me. I certainly remember him and I developed patterns of behavior and ways of thinking about education, training, and care of patients which have characterized Stead men over the years." Jeep Pierce was one of the persons destined to be a leader in anesthesiology. I enjoyed watching his growth both as a person and as a professional. I am here today to share with you some of my thoughts about education and training because Jeep believes that attitudes are as important as facts in the development of anesthesiologists. If he had not believed this he would not have selected me to give the Rovenstine Lecture.

Medical schools are complex institutions with roots in colleges and universities and branches in the real world of medical practice and services to people. We do not fit easily into the rest of the university. Because our services to people require our clinical units to function year round, our teaching schedules differ from the rest of the university. Because of the complexity of our operations, we need dedicated, capable people, M.D.s and non-M.D.s who can perform needed services. In the rest of the academic world, the definition of faculty is easy. They are persons who teach, do research, and write scholarly papers and books to achieve tenure and rank. This definition of faculty does not fit the needs of medical schools and their hospitals. We need doers as well as scholars. Duke's long-time dean, Wilburt Davison, had a workable definition. He said that anyone in the medical school who did his work well and who could not easily be replaced belonged to the faculty. One did not need to teach or write papers. I would add one additional quality. Because of the number of talented persons flowing through our institution, those we keep should perform a levels achieved by only 3% of our output. The institution should be certain that we keep the best people. They don't have to do any one thing. But they have to do it well.

* Professor and Chairman Emeritus of Medicine, Duke University, Distinguished Physician, Veterans Administration.

Received from the Department of Medicine, Cardiovascular Division, Duke University Medical Center, Durham, North Carolina 27710. Accepted for publication December 11, 1984.

Address reprint requests to Dr. Stead.

Key words: Anesthesiology: education. Education: medical students; residents.

In my experience the dedicated, superior clinicians, in great demand by numerous practice groups, who want to teach and set an example of service to our young people are the hardest to identify and keep in the medical center. Space and money will hold the scientists, and they have no place else to go. Recruiting and holding outstanding clinicians was my greatest challenge as a department chairman.

Many departments have attempted to establish a strong science base and gradually add distinguished clinicians. My own bias is to start with clinical strength and gradually add a science base related to the clinical activities. Duke was the first medical school in the country to achieve excellence without major support from endowment or state funds. What endowment funds there were went to the preclinical departments. The clinical departments had to survive on their own bottoms, and they were responsible for paying their own bills. I was one of the few professors of medicine who had to review each morning bed occupancy and bestir myself if it fell to a nonprofitable level. Departments at Duke charged their senior clinicians a fee to provide money to support the constant flow of superb young clinicians through the system. The medical school paid $2,500 per year towards any professor that the Department of Medicine appointed. The rest of his income came from the Department. Patient dollars and dollars from research and administration supported the venture. We never had a budget for education. If you didn't teach you were not admitted to the club.

It is important in a place like Duke to emphasize the role the medical school and hospital play in allowing the faculty to obtain funds that they could never obtain without belonging to the faculty. I have brought large sums of money to Duke but have never personalized it. It was always Duke money.

Today many departments and schools are being forced to adopt much of the Duke model. They have the disadvantage of having recruited faculty who want to be protected from the rigors of private practice. They are interested in supervising students and residents but not in giving direct patient care. These schools will have to add new physicians if they wish to do new things.

Selection of faculty is a key issue. The problem is that many bright, aggressive, interesting and talented young people mature into rigid, stolid, uninteresting middle-aged persons and are called "shifting dullness" by the younger people before they reach the age of 50. There are no complete answers to this problem. I have the following suggestions.

Never employ a young faculty member who will talk about anything but his work. If he doesn't have this intensity of interest when he is young, he will talk about sex, Wall Street, baseball, and golf as he ages.

Be sure that the young man has outstanding clinical skills so that he can create income from practice and not sleep on your budget. It is helpful to avoid the coupling of income and rank. You can afford some aging professors if you have kept the budget lean, but nothing is worse than a unit where all the resources flow to old professors.

Give young men their head. Support them until they have matured. Keep incomes low so that they can be fed off to other institutions. Those who stay can remain on a program where each year they obtain less from the department budget and are more on their own. Invest the salvaged funds in more young men.

Every couple of years, check the research performance of your faculty against their peers. Note the degree of excitement in the air. Are they happy as well as productive? Only enthusiastic and happy faculty recruit the next generation of bright young men. Academic medicine is not for everyone. Many persons are happier and more productive out in the world of practice with no research or teaching responsibilities. I've gently detached these persons from the academic arena. They have been hurt and surprised and have doubted my judgment. Most of them have by now recognized that their fun really lay elsewhere and in the end have thanked me.

For those few who stay and age with you, create a social system that allows for movement and for the inevitable changes in the brain as one passes from youth to retirement. At the age of 60 I relinquished administrative responsibility and worked with young people to develop areas where our department chairmen had little interest. Data banks for clinical use, computer science, clinical epidemiology, bioengineering, and geriatrics became grist for my mill. When I was 65 I served for 5 years as the medical director and primary physician for a retirement community and health care center on the edge of the Duke campus. This created income and a continuing interest in geriatrics. This in turn led to my appointment as Distinguished Physician of the Veterans Administration. Acknowledge the changes in you and others. Profit by the change.

The selection of students is never easy. Those who jump all the hurdles and make excellent grades have frequently spent their adolescence doing what they didn't want to do. Medical school may be a continuation of this process. I have always watched for persons who have high performance peaks and have not worried about the valleys. Given the right circumstances the peaks can be broadened and the valleys lessened. I've never been interested in the students who performed brilliantly on examinations and were slothful in the clinic. Medicine is a service profession, and the enjoyment of productive work is the quality I search for.

The Department carried on a variety of research programs extending down into relevant areas of basic science and up into clinical testing. We exposed our interns and residents to persons enjoying research. We never required our residents to spend time in research. It was there for those who wanted to become excellent physicians. There was, of course, cross-over in careers. Many who disavowed research as students and interns became full-time investigators as they matured in the program. Others who spent early years in the research laboratories went on to care for people in a variety of community activities. I respected them all. I wanted them to perform at an excellent level, be it in academia or in the broader community.

Medicine is a profession. Members of the medical profession have agreed to live differently from other persons in our society. Physicians have an ethical code enforced by themselves to care for all people—to care for them when they are sick, hostile, demanding, rich, or poor. It is this obligation accepted by us that requires us to live differently from other members of society. Being well educated, a good manager, a graduate from a prestigious business school, and a rich man does not make you a professional. If physicians become businessmen, work an 8-hour day, and are interested only in the profit motive, they cannot claim belonging to a profession. Other persons have no difficulty in perceiving the difference in physicians and other persons. Few members of the medical profession at Duke Medical Center are out mowing the lawn at 5 o'clock. They are caring for the sick.

In medical schools and teaching hospitals, the words education and training are frequently used interchangeably. It is useful to appreciate the differences and similarities between these modalities and not confuse one with the other.

In a narrow sense, education and training have the same goals. Each attempts to establish new learning patterns in the central nervous system, which facilitate the performance of new tasks and improve the performance of previously learned tasks. An educational program attempts to produce a wide range of changes in the nervous system and to increase the general capacity of the neural network to store information and to move and rearrange facts. We use the word "memory" to describe the acquisition and storage of information and the word "thinking" to describe the movement and rearrangement of countless bits of information.

The goal of education is to enlarge and extend the many functional neural networks of the brain for greater storage and processing of information. Such networks cover a wide range of content: language, culture, history, art, music, feeling states, religion, mathematics, communication, *etc.* A fully educated brain contains innumerable hooks for attaching, rearranging, and using the information accumulated in the memory system. It can identify problems and solve them. The brain is attuned to profit by history, by knowledge of the great religions, and by the roles that feeling states and culture play in the affairs of man. Education strives to develop a brain capable of enjoying the day and to improve the capacity of the brain to tolerate without hostility the belief systems and behavior of other persons. Education can make the day more enjoyable, and the outcome of education is not necessarily related to the production of useful things.

Training develops the neural pathways formed by education into well-grooved and well-worn tracks that permit repetitive performances with a high degree of efficiency. Training is aimed at the formation of habits that are so ingrained by repetition that only a minimal outlay of nervous energy is required for performance. Training leads to efficiency over a narrow spectrum; education leads to a broader spectrum of competency.

High school, college, the early years of medical school, and experiences in research laboratories are oriented toward education. Internships and residencies are designed to train the physician to perform repetitious tasks efficiently. Many postgraduate posts combine research (education) with clinical activities (training).

Sooner or later most persons move from the educational base to the training base. One of the roles of the faculty is to postpone this change as long as possible. The theoretic knowledge base acquired before a heavy investment in training and practice represents the intellectual capital that must support the individual for the rest of his life. Esau was hungry and sold his birthright to Jacob for a mess of porridge. Don't allow your young men to sell their theoretic and basic science opportunities for a mess of early training.

It is useful for those of us who are engaged in the educational business to keep in mind the simple rules that have been found useful over the years. The old proverb that you cannot make a silk purse out of a sow's ear is true still today. The selection of students puts a top limit on what can be achieved. When schools like Harvard accumulated enough funds to take students from all sections of the country regardless of their ability to pay, they discovered that they had no simple rules to help them find the most able persons. Their need to identify the persons with the best potential led to the establishment of college entrance examinations and the various standardized tests for students seeking admittance to medical and other professional schools. Standardized tests were selected over the demonstrated ability shown by high school grades because of the great difference in scholastic requirements of high schools. The tests do separate out persons who have learned the most from those who have not absorbed or cannot absorb and manipulate factual material. The tests have been criticized because scoring well and achieving admission to college or professional school does not correlate closely with life-long performance. Interstingly enough, the excellence of the selection system produces a paradox. Those selected by the tests are so much alike in intellectual characteristics that other qualities account for the observed differences in their performance in the real world. Motivation, degree of compulsiveness, ability to accept authority while growing towards maturity, lack of jealousy, ability to see the problems of others, knowing when to change course, the equating of work and fun, the amount of physical and nervous energy, the ability to concentrate and relax, avoidance of drugs and alcohol, ability to follow the Golden Rule, curiosity. These other qualities of the brain—different in kind from those that solve differential equations—determine the outcome of those scoring high on standardized admission tests.

Dr. Neil Smalheiser gives an example that illustrates the statistical principles involved. "All applicants for a basketball team were given a 'test'; they had to be between 6′11″ and 7′1″ tall to be chosen. At the end of the year, no correlation was found between height and performance, not because height is unimportant to the game but because the test itself lowered the variability in height among the players, so other factors accounted for relatively more of the variability in performance."

Since input is the single largest factor in determining output, there is much discussion about who should be admitted to medical schools and residency programs. Physicians treat diseases that occur in persons and care for persons when they have problems not responsive to scientific medicine. Since there are more unsolved problems than solved problems, the major activities of physicians are directed toward helping patients traverse this vale of tears with the least suffering and pain. There is an outcry for more physicians who will care for patients with chronic diseases that are not presently curable. The long-range goal of the medical profession is to eliminate disease by the use of specialized knowledge. When this occurs, caring physicians will have a reduced role and this role may well be filled by others than physicians.

For the time being we need both caring physicians and those capable of applying the sciences to prevent and cure disease. The wide diversity of medical schools assures that we continue to graduate a very heterogeneous output.

There have been a few programs that have reduced the requirements for admission to medical schools and have placed some of the basic science courses back in the college. Such a move can be defended on logical grounds, but my analysis produces cogent reasons why medical students will not be selected after the second year in college and why the basic science curriculum in medical schools will not in my time be truly integrated with the undergraduate premedical curriculum. When I joined the Emory medical school faculty in 1942, I was smart enough to know that if we selected bright, energetic, interested people and gave them an exciting educational experience during medical school, they would carry out their professional duties in excellent fashion. They would perform as well as persons who had had the traditional 4 years of college. I knew that it did not make much difference whether they commenced their medical experience immediately following high school, part way through college, or after completing college. One reason that it did not make any difference was that if a student omitted 2 years—out of the college curriculum, for example—that student could return to the courses he had missed following medical school. The student would have the time saved by the leaving-out process. He would not have used up any of it. As a matter of fact, that student could benefit economically because he could be a part-time physician while taking the last 2 years of college. There is no reason that one cannot pick up education at any level, learn what is to be learned, stop, go back, and do a variety of things in a variety of sequences. I presented this idea to the Emory faculty. The next day the president's office called and requested that I see the president that afternoon. He said, "Now look, Gene; we've got an undergraduate school in which 75% of the students want to go to medical school. We have a problem with financing this school and, at the undergraduate level, the biggest income is tuition." He continued, "Now you get back to the medical school faculty and you tell them that you had been kind of daydreaming. You now know the facts of life; no Emory student is coming to Emory medical school who does not have four years of undergraduate Emory tuition."

The second phenomenon working against this undergraduate medical school integration relates to the fact that the medical school has certain advantages over the rest of the university. The medical school has certain "perks." One of those perks is that the student body has already been screened. Because they have had 4 years of college experience and have built an academic record that is fairly easy to assess, the medical school can select the students who will cause the faculty the least trouble. One of the most interesting things about all faculties is that they always select students who will not cause them trouble. That is a major criterion of selection for medical school. I had this highlighted to me when I started a physician's assistant program. I selected people for that program who actually wanted to provide medical service. These students took quite a bit of care but they did become good physician's assistants. When we, for financial reasons, had to go to a degree program, things changed. Instead of having our introductory courses taught by physicians who were going to teach people to give service, anatomy had to be taught by the Anatomy department, physiology by the Physiology department, and so forth. Very rapidly we enrolled a student body who would not give any of these disciplines any trouble. That truly became the major criterion for selection. The desire to become part of a service profession became irrelevant.

I do not foresee more integration between the basic sciences taught in college and those taught in medical school because of the unwillingness of our basic science faculty to be combined with undergraduate science departments in any meaningful way. If one looks at the salaries in the medical school, by and large they are higher than those offered to the college faculty. Then if one looks at the availability of laboratory space, the availability of time for research, and a whole range of other factors, the medical school is a more favorable environment for a faculty member than the university-at-large. Therefore, our basic science faculty are going to resist for as long as possible moving out of the protected medical school environment. So I see no way in which real college–medical school integration on a big scale is going to occur.

Another phenomenon that makes it difficult to have a more sensible medical school curriculum is that there are no facts that can be taught in the first year that are really essential to clinical medicine in the seventh year. There simply are no such facts. By and large, the clinical faculty at Duke made an attempt to free our basic science faculty from having responsibility for teaching any facts. We simply said that any facts that the students do not know when the reach the clinical portion of the curriculum that are important to medical care and practice, the clinicians will teach them. Our basic scientists should concentrate on concepts and symbolic languages. We wanted the students to have fun with the basic sciences so that when they had seen what clinical medicine was all about and had learned to appreciate the limitations placed on medical practice by lack of knowledge of fundamental processes they would want to come back to have more fun with the basic scientists. We wanted students to have a positive experience and to become enchanted with the wonder of science so they would be more fun to work with, be more flexible, know more, and be more useful in the clinical clerkship and beyond. We honestly believed that the basic scientists interacting in a positive and stimulating way with students would have given us a much better product. We would then have been in favor of more basic science, not less. We freed the basic scientists completely from responsibility for any factual information. This experiment was not successful, and I could not understand why for a long time. At first I thought the basic science faculty were just not smart enough to understand what we wanted them to do or, rather, not to do. Well, I went out and circulated among them, ate with them, sat with them, and listened to them. They were not dumb. They were extremely smart. So I had to give up that simple explanation. The true explanation finally dawned on me and it has to do again with position in the medical school. The basic science faculty were afraid that if someone heard that no single fact they were teaching was essential they might be demoted to that college system with less perks. That is the reason they will not give up these facts. They simply keep saying that these are important facts and we have to stuff them in to protect our position in the medical school. It has nothing to do with educational philosophy; it has to do with economics, space, money and status.

Now I would like to share with you my views on how to produce an educated person. I will begin by describing the kinds of students I like to have passed on to me to continue their medical education. You must appreciate the fact that I cheat a little bit because I stand one step further along in the system than people who take freshman medical students. The students I work with and interact with during their clinical education and residency training are for the most part phenomenally bright; consequently my life has always been easy and very enjoyable. But let's think about what the essentials ought to be and what students should gain during both their college experience and during the basic science portion of medical school.

I think the first thing an educated person has to have is an ability to concentrate. I do not believe that any person can perform optimally or fully use his mind if he cannot concentrate until a task is finished. I would put very high on my list of characteristics that an educated person must have the discipline to concentrate and to complete the task at hand. One can gain this ability in many ways. I learned to concentrate when I was enrolled in a Latin class. My first crush happened to be on my Latin teacher, who obviously never knew that I was affected. I really wanted to do well in that Latin class. She was a stern disciplinarian, requiring that we learn a substantial amount of Latin each day. At that time, school ended at 1:30 and I was always in a hurry to get out in the woods to do the things I liked to do. But I had that Latin in front of me. That year I learned to tackle a tough task, complete it in a short time, and go on to what I wanted to do. Latin was one of the most valuable learning experiences I have ever had.

The next characteristic of an educated person is that he can read. I would, of course, put first emphasis on whatever primary language one uses. In this instance it would be English. One must learn to read with understanding; one must learn to read with reasonable speed. Certain problems such as dyslexia require special accommodations and educators must appreciate that there is a wide diversity in learning patterns. Some students can follow traditional learning patterns, but with others the traditional model will not produce a good result. But overall, reading and being able to understand what you have read in the English language is the second characteristic I would like to see. Closely related to reading ability is of course the ability to communicate through writing, which is another crucial ingredient to achieving what I would call the "educated state."

I do think languages should be emphasized through all of education. One of the roles of the faculty member is to identify what things a student can read and whether or not he has the language preparation to open up the areas in which he wants to achieve excellence. Today, of course, we are not as concerned with translation or the ability to speak other foreign languages as we are concerned about the student's ability to speak symbolic languages. Therefore, I would say that one should be certain that students know what areas are excluded from their range of activities when they cannot read certain symbolic languages. I think this is particularly true when one enters the research laboratory. A student will not benefit from a laboratory experience if he is merely a pair of hands. I believe that many forms of basic sciences can be taught as languages and that that ability to teach these sciences as languages is much more important than teaching their content. It makes little difference whether one has memorized chemical facts if he can read chemical journals and chemical texts. It makes little difference whether a student is already versatile in the use of computers if that student has the basic ability to learn quickly by reading, listening and experimenting with a new machine. I think the genetics door is opened up by a special kind of language; that is why genetics is an academic discipline. Genetics can be taught as a language, and this approach obviates the necessity of mastering the entire content of genetics. What the student needs is the language preparation to assess that material when he needs it.

One of the things we urged our basic science faculty at Duke to do was to experiment with approaching the basic sciences in this fashion: what does a biochemist do with a kind of biomedical problem? How does he get into it? How does he analyze it? How does he read about it? How does he go to the laboratory with it? We did not really care if this approach left a large, large quantity of unlearned biochemical facts. We tried to get our physiologists and our microbiologists to take this same approach. The end result of this experiment can be summarized very quickly: we had an absolute failure. The basic science faculty could not free themselves from fact teaching in order to take this broader approach.

I believe that any question that has a definitive answer is a form of memory. When Dr. Philip Handler and I, who collaborated on many ventures, got together, I used to tease him about never asking any thinking questions. I said this because there was always an answer to the questions he would pose to the students. The difference between memory and thinking is that memory is an accumulation of facts; thinking is the movement of facts. If you begin to move facts, you discover that you can build buildings that no one has built before. One of the problems with thinking questions is that they put the instructor at risk. You see, there is no assurance at all that our bright young students cannot construct a better means of approaching our thinking questions than we can. Faculty members must be willing to accept the potential of being aced when they ask thinking questions.

In terms of the educational process of the future, I doubt that we will discover much that is new. The importance of many of the educational principles that we already know will be reinforced. One of these principles relates to the difference between the student who is permitted to do his own learning under the guidance of someone, as contrasted to the student who sits passively while the faculty member does the work. The difference between active and passive learning has been known for a long time, and it certainly has been relearned hundreds of times. The second principle we are going to relearn is the forgetting curve. That is a great curve. Once one truly appreciates the forgetting curve, he will say, "Let's put the information where it can be retrieved and lick the forgetting curve." All of us have done this in the past, but we are getting newer and better tools with which to do it. Each of us scans book and journals to see what is in them—to learn where to find a fact when we need it. The general notion that you can protect against ignorance by continually packing in facts assumes that there is no forgetting curve. We will rediscover the forgetting curve.

I also think that we will rediscover the concept that teaching attitudes is more useful than teaching facts—acknowledging that teaching facts is different from creating new information and storing it in retrievable fashion. I would have to say that all my life I have been an attitudinal teacher. My students have always said that they can never remember me teaching them anything. On the other hand, if one would ask them whether they remember Gene Stead, very few will have any trouble identifying who I am. Because everyone else at our institution was teaching facts, it was not necessary for me to go around teaching facts. Therefore, I could have a good time doing useful things with the students, and they remember me for that. The fact-teachers have freed me up. Because these students can have fun with me and because we can play intellectual games that teach a way to approach thinking questions, they are learning attitudes that will be much more useful in the future than facts.

This brings me to the concept of positive and negative signs that students assign to a given experience. The sign of any venture is much more important than the content of the venture. I remember a person from another country asking me about the content of our medical school curriculum. Aftr a brief discussion, he said, "I don't need to ask you this; I can see how many hours these courses have in the catalog." I said, "That's not going to do you any good. You've got to appreciate that part of those hours are spent in such a way that no student will ever again want to return to those areas." The sign was strikingly negative. So whatever you do in the teaching world, the sign must come out positive. The student needs to feel that the venture was worthwhile.

I believe that the faculty has only three responsibilities: selecting students, creating places to play intellectual games, and sharing in the excitement of playing those games. In the course of this interaction, the faculty has to define excellence. Determining or identifying excellence is an absolute requirement of the faculty, and it is one of the few educational functions for which faculty have sole responsibility. The student has no way of objectively assessing his own performance. There are many ways to determine and communicate excellence. If one nevers offers anything but criticism, everyone will run away from him. If one never provides anything but praise, students will fall on their faces. In the final analysis, the faculty has to determine what excellence is and how to demand it. The faculty will not get it unless they require it, and every time a student gives a performance that is not excellent and not called to the student's attention, the faculty member is throwing away his time, is wasting the student's tuition, and is stealing a portion of the student's birthright.

Many faculty confuse the issue of requiring excellence with the fear that those who require excellence will be unpopular teachers. That, in my experience, has not turned out to be true. In my teaching career, the Department of Medicine was always the most demanding and the most popular experience in the clinical areas. The question of popularity often revolves around doing busy work. If students have rigorous experiences that they know are useful and getting them somewhere, those experiences will be highly regarded.

Of the many attitudes I would hope medical students would develop, I think it is important that they feel comfortable saying, "I don't know." I became interested many years ago in the fact that compulsive learners are never original. Compulsive learners who can't say "I don't know" are at the mercy of the expert. The compulsive learner always says, "I've got to go read that paper"; he cannot say "I don't know." I think it is important to teach students that "I don't know" is always an acceptable answer. Then the question becomes "Is it worth changing the 'I don't know' to 'I do know'?" That is a judgment call that the faculty can help the student to make. Being able to say "I don't know" with relative ease is the greatest single freedom, and people in medical school have it to a greater degree than do people in most other portions of the university. Medical schools are not perfect but we do have more people who can say "I don't know" comfortably than are usually found in educational ventures.

In addition to being able to say "I don't know" comfortably, medical students should learn to say "I was wrong" with comparable ease. I have made it a lifelong habit to assume that I was the cause when things went wrong. I have not always been the cause, and, after proper examination of the system, I might let myself off the hook. But I have always found it more useful to assume, at least initially, that the reason the medicine came out poorly was me. I have certainly never placed the blame with the patient. The patient came to be because I was supposed to be an expert; I could not require him to be an expert. I think it is important that students can examine a situation that has gone wrong without being defensive, because there is no way one can practice clinical medicine and not make mistakes. As soon as one appreciates that, tolerates it, and profits by it the better off he is.

I doubt that there are many educational principles or phenomena in the learning setting that will be new in the future. Many of the principles we already know will be continually relearned. I do think we might make some progress in remembering the forgetting curve and in developing retrieval systems that will be useful. I do not think for a minute that the faculty will give up trying to stuff students' heads with facts. Traditionally, that is what they think they are paid for. And, in the end, unless we can convince them to the contrary, they will continue their emphasis on teaching facts, regardless of the futility of that approach.

-6-

MEDICINE AT THE CROSSROADS — WHAT LIES AHEAD

by Edward R. Annis, M.D.

MEDICINE AT THE CROSSROADS WHAT LIES AHEAD

Edward R. Annis, M.D.

I brought with me today the most important book of my library. It is very thin — only thirty-six pages. First printed in 1776, it has been credited as a major factor in uniting early Americans in defense of freedom. Its author: Tom Paine — its title, *Common Sense.* In his introduction, Tom Paine wrote the following: "Perhaps the sentiments contained in the following pages are not yet sufficiently fashionable to procure them general favor." "A long habit of not thinking a thing wrong gives it a superficial appearance of being right and raises at first a formidable outcry in defense of custom." "Time makes more converts than reason." I suggest to you that once again the defense of freedom demands common sense.

When I was in medical school, infectious diseases were the leading cause of death in the United States. The introduction of sulfanilamide in the mid-30s and penicillin in the early 40s opened doors to what today allows multiple and safe invasions of almost all areas of the body for diagnosis, medical treatment and surgery. Coincident to these discoveries, private health insurance came into use. Millions of Americans purchased health insurance, like other insurance to protect them from the extra cost resulting from major illness and accidents. Doctors charged a fee for their services. Some patients couldn't pay. Some didn't pay. Some of the more affluent and wealthy paid more than low income workers which made it possible for doctors to afford to provide many services for which they were not compensated. It also enabled doctors to purchase needed equipment and to attend medical meetings to keep up with rapidly developing new ideas. That system had evolved gradually and parallel to medical advancements and it worked pretty well until government intrusion via Medicare and Medicaid in the mid 60s. It has been this government intervention which has changed your role as medical leaders today. Unlike earlier years when medical leadership concentrated on matters medical, the future role of organized medicine is being dictated by our profession's ability and willingness to recognize and adapt to those turbulent forces currently operating in the social, economic and political as well as the scientific climate of today. Many and varied are the contributing factors which up until now have provided the majority of American people with greater availability and greater access to quality medical care than ever before experienced by any people, anywhere at anytime in the history of the world.

One factor stands out as a fundamental — namely, freedom. The freedom of patients to choose their own doctors and the freedom of doctors and their patients to choose their hospital and decide on the most appropriate treatment. Common sense forces us to recognize that there are powerful forces at work today to take away those freedoms and in the process threaten to destroy our great system of medical care. They are taking choices away from doctors and their patients and putting decision making into the hands of those who pay some or all of the bills. These forces did not arise overnight and their existence is no accident. In a democracy such as ours, things don't just happen, they happen because people make them happen. If costs are rising, and they are, if excessive costs must be curtailed, and they must, if public surveys reflect diminishing confidence in our profession, and they do, reason and common sense dictate that attention must be directed toward the major contributory elements which have created the problems.

As one who has lived through these times of turmoil, may I recount a little history. The forces hostile to medicine started over 40 years ago with the Wagner, Murray, Dingle Bill which would have established an English style system of socialized medicine whereby government would own and control the hospitals and doctors would become employees of the central government. Despite continuous and persistent pressures, the proponents of this approach were unable to convince the American people. Faced with repeated failures, the advocates of central government control changed their tactics and their political approaches. Their reasoning took a piecemeal approach, never losing sight of their ultimate objectives. They said, "Let us take care of all of the elderly and have the younger, working members of society, the taxpayers, foot most of the bill." They reasoned, once the program of entitlement is in place and working, those who pay the bills will want to be included in the benefits for which they pay in taxes and then the public at large can easily be persuaded to expand the system which we seek. And so it was, that in the early 60s, promising a single standard of quality care and under the popular theory that medical care is a universal right, our government established Medicare and Medicaid to provide health care for the elderly and the poor. That same legislation took patients out from doctors' offices, specifically limiting coverage to more costly, in-hospital care. Simultaneously, government further subsidized medical care by promising tax-deductible business expenses to employers for providing health insurance as a non-taxable fringe benefit for their employees. Hospitals were promised cost plus reimbursement and doctors promised to be paid their usual, customary and reasonable fees.

Assured that bills would be paid, all segments of the population responded. The result was that millions of Americans who had previously been denied availability and access were given the kind of care that saved lives or enhanced the quality of those lives. Hospitals were built, more doctors were educated and technology stimulated. America became preeminent in the world in providing health and medical care for its people.

The 1960s and 1970s were affluent days for almost everyone, basking in the warmth of the promises of the Great Society. What went wrong? Costs skyrocketed and then government leaders and businessmen began to realize that their promises had exceeded their ability to pay. They had not anticipated the cost of a steadily increasing population with a net increase of more than 2 million persons each year. They had not anticipated the greater and increased demand on the part of the elderly, many of whom previously denied care, were now receiving it under Medicare and Medicaid. They had not anticipated that the elderly, comprising 11% of the population, would consume more than 1/3 of all money spent on the nation's health care. They had not anticipated that better medical care would enable many people to live longer and better, but to require more health care for the chronic diseases and infirmities of their later years. They had not anticipated the ever-increasing cost of new knowledge and the tools of space age medicine. They had not anticipated the revolution in health care expectations. The public increasingly demanded and received the best medical care which itself was inexorably rising in cost because of the rapid scientific and technological breakthroughs.

In his parting message to the American people after two terms in Office, President Eisenhower said, "Political balance is threatened when interests in the country wield unchecked power, either as a result of growth over time or as a result of a specific crisis." Our successes have created many of our problems, so that the spotlight has shifted from availability, access and quality to concentrate on the issue of costs. This concentration on costs has produced the crisis that the socializers have long sought. A good friend and former President of the Florida Medical Association is Dr. Robert Windom, Assistant Secretary to Dr. Bowen in the Department of Health and Human Services. In Washington about a month ago, I asked him, "Bob, what kind of progress are you making against the socializers?" His reply, "Every once in a while, we make a little dent." Remember, that over the years, that entrenched bureaucracy protected by civil service has steadily grown in strength and numbers. Its people have seen presidents and appointed secretaries come and go. It makes little difference whether the Administration is Republican or Democrat, they continue in their determination to regulate and control. You and I may get together to elect a conservative to Congress. The newly elected goes to Washington from hometowns, large or small, accompanied by one or two trusted assistants. Once in Washington, he or she must seek a staff, invariably from the Washington pool of career government workers. When appointed to various committees, the newly elected then request of their new staff background material for adequate briefing and information, and from what source is this obtained? You know the answer — the bureaucracy. Many legislators have admitted that they have been in Washington several years before they realize that they have been had. To overcome objections raised by the medical profession and to gain public support, Congress wrote into law a prohibition against any federal interference in the practice of medicine or in its financing and guaranteed free choice to patients and physicians. These promises have been circumvented repeatedly by rules and regulations emanating from the HHS bureaucracy. What they have been unable to obtain by direct action through liberal legislators, they have accomplished by having friends in key committees package their plans in budget reconciliation actions or via continuing resolutions. By these questionable procedures, they have been successful in by-passing the normal process of discussion, deliberation and debate that allows input from interested partys and the public. Medical care is the only segment of the nation's economy subject to price controls. We have been subject to fee freezes, originally promised to be lifted, only to be extended time and again. Arbitrarily determined diagnostic related group reimbursement for hospitals are now threatened for doctors. Discriminatory separation of physicians into participating and non-participating roles. Those among the non-participants in government programs, are now to be paid less and subject to onerous regulations and paperwork. The bureaucracy constitutes a formidable force of Washington personalities. I have been on programs with three of their members. They insist that they have the answers. One of them, Kevin Moley, introduced as a key official in setting government policies related to competitive health delivery systems, stated, "Capitation is the future because the alternative does not exist." "It offers us the opportunity to capitate the Medicare programs in total!" Mr. Moley continued, "In order for capitation to succeed, in order for this Administration to fulfill its mandate in this area, we are determined to provide a Medicare package, an incentive of benefits to give sufficient reason for the 30 million beneficiaries to move from the comfort of their own predisposed ideas with which they grew up in the fee-for-service segment to move with some degree of comfort to TEFRA and at-risk contracts."

They have long since stopped calling us doctors. We are now providers and our patients, they're consumers. As leaders we must remind physicians and their patients, the American public, that these government planners are the same people who estimated the costs of government programs — assuring Congress that they could easily be afforded. These are the same people who convinced Congress to encourage hospitals to build, to expand, to renovate, to provide more beds, assured of payment for all costs, plus a small profit. These are the same people who said we want to do away with charity and we will pay doctors their usual, customary and reasonable fees. These are the same people who prepared the speech for then President, Lyndon Johnson, proclaiming to the American people that we needed 50,000 more doctors to supply their medical needs. Now, it is these same people who are saying, we have too many hospitals, we have too many hospital beds, we have too many doctors, medical care costs too much. Their answers to existing problems are more rules, more regulations. They are determined to control how medicine is to be practiced.

In addition to the bureaucracy, there is a second force with which we must contend — namely, the business community. Under ordinary conditions they would be our allies against oppressive government, but government actions have placed them in a real bind. On one hand, there are escalating costs, foreign competition and the need for new tools and technology. On the other hand, government is failing to meet its obligations and is increasingly shifting medical costs to the private sector. It is not surprising that business coalitions have been formed to limit increasing health care costs. We must remember, however, that the business community is not a unified force. One segment dictated by a bottom line mentality, goes along with the bureaucracy and liberal members of Congress that want to put further restraints on the profession. Also to be included with this group, are the entrepreneurs who envision an opportunity to participate in the $450 billion per year spent on health care. They would sell your services at a discount so that they could make a profit, even through they contribute nothing to the care of the sick and injured.

This power in some segments of the business community, however, is somewhat mitigated because of the natural reluctance that most business people have against government inroads into the private sector. And then there's a sizeable segment of the business community that provides the research, the development, the tools that are characteristic of space age medicine. One large and powerful member of that group is the pharmaceutical industry, which today spends in excess of 100 million dollars in getting some of the better, new drugs finally to a marketable stage. So we can look for some strong allies from the business community, if and when we are able to mobilize our efforts and get our story told.

I envision the third force as one with the greatest potential — namely, the force of the American people. Admittedly unorganized and frequently divided, they still don't really understand the problem. They have not as yet heard all of the problems which would indicate that their health care and the health care of their loved ones are being placed in jeopardy. It is time for us to appeal for common sense. The biggest obstacle to a reasoned and reasonable program to assure health and medical care for all of our people is big government itself. The American public is aware of the tremendous federal deficit and the majority can be persuaded to reject government solutions if reasonable ones are presented. It is one thing for government to say they're going to put a lid on medical costs while at the same time they promise more benefits to more people. This started in the mid 70s when they wheeled a man into the Ways and Means Committee of the House who was suffering from end-state renal disease. Without any major input from the medical profession, they said — anyone with this disease, rich or poor, if they have this disease, we're now going to put them under Medicare.

As usual their projections were only approximately correct. They projected the first year would cost about a 100 million dollars, that it would slowly rise to over a 150 million and over a period of time it would level off at around 350 million dollars a year. Last year the toll exceeded 2 billion dollars! After people have been on Social Security for disability for a period of 2 years, they now qualify for coverage under Medicare. Organ transplants, now numbering in the thousands, reflect great technological advancements, but they are also very costly and a large segment of those receiving transplants of heart, lungs, liver, kidneys, pancreas, are also an additional drain on a limited source of Medicare dollars. The past three years have seen a cutback of approximately 30 billion dollars in Medicare at the same time that government leaders are promising more to the elderly American people. Isn't it time that we asked for a little common sense? Further billions are to be cut from Medicare at a time that the elderly are the most rapidly increasing segment of our population. Of those over 65, those over 75 are increasing in greater numbers. Over 2 million have reached the age of 85 and something in the neighborhood of 210 reach the age of 100 every week.

The records of medical success have been truly fantastic. Surveys of the American people have indicated that, though they are really concerned about the escalating cost of medical care, they're not really concerned about that percentage of the Gross National Product that goes for medical care. Repeatedly, surveys have indicated that the American public feels that government spends too little, rather than too much. Isn't it about time that we ask, does not common sense dictate, that if government dollars are limited, they should provide adequately for those in need of help, rather than be distributed in lesser amounts to all who have passed a certain birthday? Does not common sense dictate that limited government dollars in any program should not go to the rich as well as the poor. Most Americans have spent more on the purchase, running and maintenance of their automobiles than they will for the total cost of health insurance and medical care for their lifetime. Recent data from the Carter Center of Emory University in Atlanta, indicated that 80% of all deaths in the United States each year are due mainly to lifestyles or self-inflicted health hazards. They further report that deaths can be attributed to 13 distinct health problems that account for 84% of the total cost of direct personal health care. If people insist on self-determination and self choice, should they not be individually responsible for their actions and pay the price for them, especially when they can afford to? Why should tax dollars be used to fund and support ill-advised lifestyles? Why should doctors and hospitals be expected to provide the services and then also to subsidize them? Great numbers of the members of our affluent Society could live longer were it not for the fact that we eat too much, we drink too much, we smoke too much and we exercise too little. Tobacco is probably the greatest producer of preventable disease with which we deal and yet it is financed and supported by our government. A recent article in *Time and US News* highlighted the role of alcohol in our Society, indicating that we have over 100,000 premature deaths every year costing multiple millions of dollars. You are aware of the record of the holocaust on our highways. Every week over 900 people are killed, and some 65,000 are put in the hospital. These reflect the demand side of an ever growing population. And, when they become ill, because they are human, whether it is from alcohol or tobacco or lack of exercise, when they become ill and when they come to a hospital, what do they say, "Doctor do everything you can, and spare no expense."

Most of your know that in South Florida we have the unenviable reputation of being the worst segment of America in the area of malpractice. Imagine if you were a young obstetrician and because of the highly litigious nature in our area of the country, you want to protect yourself with a million to 3 million dollar coverage before you start delivering babies, and you are faced with a premium in excess of a $150,000 a year. Established neurosurgeons are charged in excess of $200,000. Just this evening, from two of our officers, I learned a statistic I have never heard before, but they now tell me we can confirm it. At the University of Florida in Gainesville, we turn out 2 neurosurgical residents every year and for 10 years in a row, not one has stayed in the State of Florida.

Others of you from different parts of the country have similar stories to tell. Many of our residents being trained will become some of the finest technical and caring physicians that have ever been turned out. Many communities where they are educated are being denied continuity — the continuity that has long characterized American Medicine. A year ago in Miami we had 8 trauma centers, now we have one. People will die that might have been saved. If the American people knew these things, they would say — wait a minute, we don't like what's going on. Who is going to tell them, unless we do it. There are many ways in which a story can be told. We can do it through our organizations, such as AMPAC, a political action committee of great value. AMPAC will help us to select and elect those who at least listen and hopefully can understand the position of American medicine. But there is a greater force that we have never used successfully. They are the in excess of 3 million people seen every day by their doctors in this country. If we could just get our doctors to begin to talk to their patients. Everyone of you has stories to tell comparable to those I have made reference to. In every state, in almost every area, we have stories that we can begin to share with our friends, our neighbors, members of city clubs, our church clubs, as well as elected representatives. And, like a good story, once you begin to tell these stories, they too will be repeated by other people. It is time for us to let the American people know we still have their best interests at heart, that our prime concern is our ability to continue to expand our knowledge and our skills and to make them available to those in need.

The current issue of *Forbes Magazine* indicates that General Electric's division that produces Nuclear Magnetic Imaging and other equipment is cutting back on its research and development because hospitals under DRGs are no longer able to continue to upgrade the tools they have for diagnosis and treatment. These stories aren't generally known by the public at large. We do have a story to tell and we had better start telling it soon, because I am convinced that there are a great number of people out there who would like nothing better than to be able to dictate to us. There are thousands of physicians in this country today who have never been to a first-class medical school. At the same time that government dictated to the medical schools of this country that they should expand their facilities to train more young people for the future, they lowered the barriers to allow less than well trained people to come into the states and to be licensed to practice medicine. At the present time, there are still 38 diploma mills off the Florida coast in the Caribbean, and the number of students currently enrolled exceeds 16,000. Once again, I would suggest that common sense dictates that we better begin to let the American people know that it is their health and the health of their loved ones that are at stake. If they understood, I'm convinced that the American people would be very upset to realize that their government and a segment of the business community would deny them access and availability to an ever-increasing quality of medical care because of bottom line pressures. We must let them know that medical care in the future will cost more not less. We're taking care of more and more people every day. Common sense tells us that there is no way that we can take care of more people, continue to educate more young men and women for tomorrow, continue the continuing medical education that is so essential for all of those still in the practice of medicine and continue to provide for an ever-increasing demand side of a growing population without having it cost more, not less. We must emphasize to the American people that, as in the past, we still today feel that everyone in this country who needs medical care should have it when they need it, as long as they need it, whether or not they can pay for it. We also should ask if common sense doesn't dictate, that those able to do so, should provide for their own health care either directly or through the mechanism of insurance and leave the government its legitimate responsibility of providing for those unable to provide for themselves.

This little book, *Common Sense,* was written by Tom Paine to arouse the populace against the multiple insults from which they were suffering at that time. Today, American medicine is being insulted on every side, to the point that it threatens our ability to continue to provide quality medical care to our people. I repeat Tom Paine's admonition that "A long habit of not thinking a thing wrong gives it a superficial appearance of being right and raises at first a formidable outcry in defense of custom." "Time makes more converts than reason." I suggest to you that once again the defense of freedom demands common sense.

-7-

BALANCING THE RISKS OF NEW GASES

by John F. Nunn, M.D.

BALANCING THE RISKS OF NEW GASES

John F. Nunn, M.D.

I AM ONE OF THE NEW GENERATION OF ROVENSTINE LECTURERS WHO NEVER KNEW THE MAN.

Dr. Rovenstine was one of the earliest trainees of Dr. Waters in Madison — a member of the celebrated Aqua-alumni or droplets and he was certainly the first to set up in 1935 a major second generation university department — in the mould of Wisconsin and a model for Residency Programs in the USA and throughout the world. Over 50 years ago, the basic principles of practice, teaching and research were firmly established and have continued with remarkable uniformity to the present day.

Perhaps his most important memorial is the cadre of former Bellevue residents who became Professors and Chairmen of Anaesthesia Departments, through whom the lineage of Waters was transmitted, (through Rovenstine in Bellevue) to become the third generation of Chairmen from Waters.

Though deeply conscious of the honour, it is not easy for a foreigner of my generation, either to pay the appropriate tribute to a man of Dr. Rovenstine's eminence, or to provide a fare which is cost-effective for the time of so many distinguished men and women in this enormous audience.

Shakespeare's seven ages of man can be adapted to seven ages of a medical scientist. The 1st is working by oneself without recognition — alternatively known as the angry young man. The 2nd age is working with recognition of one's genius and this is perhaps the best age of all. The 3rd age comprises the supervision of the work of others and can be singularly exasperating. In the 4th age, one is invited to write reviews and chair symposia. By this time one is usually far too busy talking about one's previous contributions to do very much original research oneself. The 5th age is that of the Departmental Chairman and involvement in National Politics. Some see this as a happy release from research which no longer amuses. Others mourn the loss of their activity at bench level. A third group, including several very distinguished members of your Society, has resolutely refused to enter the 5th age. The 6th age concentrates on the History of Medicine and Science: only library facilities are required. The 7th age comprises contemplations and occasional pronouncements on the Philosophy of Medicine and Science: no facilities are required.

I am not entirely certain into which age this discourse can be classified but I have little doubt that my friends will tell me when I have finished.

I am no politician, and I have no direct working experience of anaesthesia in this country. However, in 34 visits and having been host to so many sabbatical visitors from this country I have gained much insight into the differences between working practice within our two countries. Oscar Wilde, in his short story, the Canterville Ghost, published in 1887, said: "...we have really everything in common with America nowadays, except, of course, language." It is strange that our fortunate ability to communicate in our respective mother tongues has still left our daily practice so very different. I believe that we have much to learn from one another in both organization and the practice of anaesthesia.

Perhaps we are learning most rapidly from you in the field of litigation for damages arising in the course of anaesthesia. Our defense subscriptions appear set to double each year in the foreseeable future. A fruitful field for the plaintiff is inappropriate changes in the concentrations of various components of the inspired and aleveolar gases. After almost 40 years of research in this area, I thought it might be useful to consider the balance of risks with gases, as opposed to vapours, in our practice.

Like many of my generation, I did not choose to be an anaesthetist, but was thrust into the practice of the specialty — in my case in the Malayan Medical Service in 1949. On the small but beautiful island of Penang in the Straits of Malacca and qualified just 12 months previously, I set out to teach myself anaesthesia with no-one to guide, teach or confuse. The aftermath of the Japanese Occupation left few drugs and less equipment.

There were chloroform, ether and ethyl chloride — all to be given on the open mask —

thiopental intravenously, procaine and heavy nupercaine for spinals. We had a cylinder of oxygen administered in unknown quantity through a catheter under the open mask. There was one surviving endotracheal tube but no laryngoscope, no nitrous oxide, no cyclopropane, no carbon dioxide and no anaesthetic apparatus. A funnel covered with gauze was the endo-tracheal anaesthetic apparatus. Insert it in the endo-tracheal tube and sprinkle the gauze with ether, being careful not to allow liquid ether to enter the trachea. With all these primitive though effective techniques, air was the inspired gas although oxygen-enrichment was possible.

Air

It is appropriate that I should start with a consideration of air. There are many who will say that God's good air is what we are meant to breathe and it has been clearly demonstrated that, with artificial ventilation, and ether vaporized in air, acceptable arterial blood gas tensions can be maintained. There are, however, plenty of other situations where air as a carrier gas for volatile anaesthetics is quite inappropriate and can result in hypoxia.

Clover's exceedingly efficient apparatus vaporized ether in a closed rebreathing system. In 1877 the bag was filled with air, and expired air at that. What happens to alveolar oxygen and carbon dioxide concentrations during 2 minutes of rebreathing with such an apparatus? Pco_2 exceeds Po_2 after 90 seconds and, while this will maximize ventilation and cerebral blood flow, the arterial Po_2 would be quite unacceptable by modern standards of safety.

With most modern techniques of inhalational anaesthesia, air contains insufficient oxygen for maintenance of a normal arterial Po_2. In studies undertaken with various colleagues over 20 years ago patients were anaesthetised with halothane and were breathing spontaneously — a practice much favored in the United Kingdom, though frowned upon in some parts of the United States.

Many of the arterial Po_2 values were quite unacceptable when the inspired oxygen concentration was below 30%, and it made no difference whether the oxygen was mixed with nitrogen or nitrous oxide. 21% oxygen was quite clearly unacceptable.

The cause of the hypoxia is partly the increased alveolar/arterial Po_2 gradient and partly hypoventilation. Alveolar Po_2 can be properly maintained by artificial ventilation, and it might be thought that 21% oxygen would be adequate under these circumstances, but this is not the case.

When the patient's lungs were ventilated artificially, the alveolar Po_2 values were satisfactory and a highly predictable function of the inspired oxygen concentration. Nevertheless, it still required 30-40% oxygen to avoid hypoxaemia, because the alveolar-arterial Po_2 gradient was considerably larger than in the conscious subject. Only with oxygen-enrichment is air an acceptable carrier gas for halothane anaesthesia even with artificial ventilation, and the same applies to isoflurane and enflurane.

I think it is right that air should be given a place on the rotameter block. The choice between 100% oxygen and a nitrous oxide/oxygen mixture is too restrictive. Pure nitrogen is unnecessary and is unacceptable because of the danger of dispensing an oxygen-free gas mixture by mistake.

Oxygen

If a little extra oxygen is good then why not use 100% oxygen as a carrier gas? If the patient is de-nitrogenated and the inspired gas is 100% oxygen, then it is virtually impossible for the patient to become hypoxic no matter how gross the alveolar hypoventilation. I am sure this must have saved the lives of many patients, before the factors governing oxygenation were properly understood.

Three and one half min of alveolar ventilation gives a normal alveolar Po_2 when breathing air. This is reduced to 1 1/2 l/min when breathing 30% oxygen and only 1/2 l/min when breathing 50% oxygen. With 100% oxygen, arterial Po_2 can be maintained at the normal value with a minute volume of only 300 ml/min, and the situation merges with the phenomenon of apnoeic mass movement oxygenation. I need hardly remind this audience that the Pco_2 would increase in accord with the diminished ventilation, regardless of the inspired oxygen concentration. Today no one would advocate gross underventilation with 100% oxygen as a viable basis for anaesthesia but we must remember that hypoxia kills quickly and co_2 retention kills slowly. Hypoxia must always be our first concern. 100% oxygen may also be needed for relief of hypoxia owing to shunting. 100% oxygen also has a limited role in the clearance of gas loculi.

Perhaps of greater practical importance is the effect of breathing 100% oxygen on the stores of oxygen in the body. When breathing air, very little of the 1.5 1 of oxygen in the body is available without a reduction of alveolar Po_2 to about 40 torr. In contrast, while breathing 100% oxygen, some 2 1/2 1 of oxygen are available without hypoxia and this is sufficient for 8 minutes of total apnoea. This huge safety factor makes inhalation of oxygen-rich mixtures a mandatory precaution before any procedure that may result in temporary apnoea — such as tracheal intubation or extubation.

The arguments in favor of 100% oxygen are so cogent, that one school of thought recommends 100% oxygen as the universal carrier gas for anaesthesia. Others would add the exclusion of nitrous oxide as another reason for favoring 100% oxygen. Those opposed to the use of 100% oxygen raise 4 main objections.

1. It precludes the use of nitrous oxide.
2. It favors absorption collapse of the lung.
3. It encourages carbon dioxide retention.
4. It causes oxygen toxicity.

Let us take these objections one by one:

1. Inability to use nitrous oxide is no problem to those with whom nitrous oxide is out of favor and the pros and cons of this long established anaesthetic I will consider in a moment.

2. Micro-atelectasis was proposed as a feature of anaesthesia a quarter of a century ago by Bendixen, Hedley-Whyte and Laver.

Now computerized tomography in the hands of the group in Stockholm has shown us beyond any doubt that pulmonary collapse in the dependent zones of the lung is a normal consequence of anaesthesia. It would be expected that the collapse and therefore the intrapulmonary shunt would be worse with 100% oxygen but there is, surprisingly, no evidence that the shunt would be worse with 100% oxygen but there is, surprisingly, no evidence that the shunt is different during anaesthesia with 100% oxygen, 30% oxygen in nitrogen, or 30% oxygen and nitrous oxide. So objections to 100% oxygen on the grounds of enhanced pulmonary collapse do not seem to be very important in practice.

3. The third objection to 100% oxygen is the possibility of gross hypercapnia arising without detection. This has indeed resulted from extreme hypoventilation, accidental rebreathing and accidental administration of exogenous carbon dioxide. In most of those examples, with Pco_2 values ranging as high as 250 mm Hg, the patients came to no apparent harm, as well they might have done with lower inspired oxygen concentration, However the avoidance of hypercapnia is achieved by an understanding of the problem, by vigilance and monitoring. This is no argument for avoiding 100% oxygen.

It might be feared that 100% oxygen would abolish peripheral chemoreceptor drive and so depress breathing, particularly in patients with defective central chemoreceptor activity. However, the brilliant series of studies by Knill have shown that even light planes of anaesthesia abolish peripheral chemoreceptor drive, and so 100% oxygen can do little further harm in this respect, because these watchdogs are already sleeping during inhalational anaesthesia.

4. Finally, there is the question of oxygen toxicity. The metazoa and all terrestial (as opposed to aquatic) life have evolved to depend on oxygen — firstly for ultraviolet shielding and secondly for the greater efficiency of oxidative metabolism.

Oxygen has the capacity to form a devastating series of free radicals and other oxidants including the superoxide anion, two varieties of singlet oxygen, hydrogen peroxide, the peroxy free radical, the hydroxyl free radical, until finally it is fully reduced to water and becomes harmless. Survival of life forms in an oxidant atmosphere has only been possible by the widespread development of a host of anti-oxidant defenses including superoxide dismutase, catalase (absent from anaerobic organisms), peroxidases, the glutathione system and vitamins C and E. Although these systems will protect aerobic organisms from exposure to air, most forms of life are killed by exposure of a few days to 100% oxygen. It might therefore appear that 100% oxygen was less than optimal for anaesthesia. However, man, as a species, seems better able than some others to withstand exposure to oxygen and there is no evidence that exposure lasting a few hours does any demonstrable harm. Neonates may well be an exception and retrolental fibroplasia may result from the use of high concentrations of oxygen during prolonged anaesthesia.

So we are left to conclude that, while the case for oxygen enrichment to some 30-40% is overwhelming, the use of 100% oxygen is over-insurance against hypoxia during a routine anaesthetic and its use is often motivated by a wish to avoid nitrous oxide. Nevertheless we lack convincing evidence that it is harmful during anaesthesia, at least in adults.

Carbon Dioxide

Among the many differences between a

British rotamerter block and what can be seen in the USA is the presence of carbon dioxide. Why is it there?

The original use of carbon dioxide was to hasten induction with the very blood soluble and irritant volatile anaesthetic, di-ethyl ether. Happily those days are behind us, but carbon dioxide has acquired a new role for the rapid elevation of Pco_2 at the end of an operation during which it was decreased below the apneic threshold by artificial ventilation. But cannot this be done by simpler means such as hypoventilation or bypassing the soda-lime canister? My colleague Ivanov and I examined the time course of alternative techniques for raising the Pco_2 at the end of an operation.

Although Pco_2 can be reduced by hyperventilation with a half-time of about 4 minutes, the reverse process of raising Pco_2 by hypoventilation is not a mirror image. The half-times are not the same and the physiological principles are different. It is true that the half-times of both depend partly on the storage capacity of carbon dioxide in the body, but there the similarity ends. Carbon dioxide wash-out depends primarily on the alveolar ventilation while the accumulation of endogenous carbon dioxide must be limited by its rate of metabolic production. In total apnea, Pco_2 rises by only 3-6 mm Hg/minute and, with hypoventilation, a part of the carbon dioxide production is lost and so the rise is slower.

In practice, hypoventilation (with a minute volume of, for example, 3 1/min) is a very slow way of raising Pco_2, even when bypassing the soda-lime canister. In contrast, an increase in the inspired carbon dioxide concentration causes an extremely rapid rise in Pco_2 to a level slightly above the Pco_2 of the gases delivered by the rotameters. The simplicity of this technique for raising Pco_2 above the apneic threshold at the end of an operation has ensured the survival of carbon dioxide on anaesthesia apparatus in the United Kingdom.

The American objection to carbon dioxide is, I understand, based on the fear of accidental delivery of a very high concentration of carbon dioxide with the bobbin lurking at the top of the rotameter where it can easily be overlooked. This fear is real.

The solution is very simple. It is hoped that the new generation of anaesthetic apparatus of the United Kingdom will have an in-line flow restrictor to limit the maximal flow rate of carbon dioxide to a safe level and also ensure that the bobbin cannot rise above the middle of the rotameter scale, where it remains easily visible.

An entrenched transatlantic difference in practice is the widespread practice of unassisted spontaneous breathing during minor operations in the United Kingdom. This seems to be abhorrent to many Americans. We studied the mean alveolar and arterial Pco_2, during surgery with routine anaesthesia including opioid premedication, nitrous oxide and unassisted spontaneous breathing. To our surprise, at iso-MAC concentrations of volatile anaesthetics, the American isoflurane consistently gave slightly lower Pco_2 values than the British halothane. However, Pco_2 was often in excess of 70 mm Hg. This technique has been used countless millions of times in U.K. and there is still no convincing evidence that it is harmful. Hypercapnia does not progress with time.

Cyclopropane

The British rotameter block still contains cyclopropane but I suspect its days are numbered. Dr. Rovenstine called it the "champagne of anaesthetics" and this was partly owing to the fact that it was non-irritant and partly because of the release of catecholamines which profoundly modified its respiratory and circulatory effects. Nowadays we can do very well without the release of catecholamines. We prefer to make our own arrangements for autonomic control. However, the induction characteristics of cyclopropane are very attractive and many of our pediatric anaesthetists wish to retain it for this reason.

Two properties of an anaesthetic govern speed of induction. The first is well known: the blood/gas partition coefficient. The other property is the concentration which can be inhaled as a multiple of MAC. The values are totally unrelated to each other but speed of induction depends on both a low value of the blood/gas partition coefficient and a high value of the MAC multiple. The partial pressures of xenon and nitrous oxide which can be breathed are limited to 50% and 70% of MAC because of the barometric pressure and the need to give oxygen. The fluorinated anaesthetics are irritant to the conscious patient when breathed in concentrations ranging from 1-3 MAC, while diethyl ether and methoxyflurane are far too soluble in blood for fast induction.

In a class by itself is cyclopropane. Blood solubility is very low and it can be breathed in a concentration of 6 MAC and maybe more. My first publication, 34 years ago in the *Medical Journal of Malaya,* described a technique for totally closed administration of a mixture of one gallon of oxygen and one gallon of cyclopropane. It was intended for very short operations. Consciousness was lost in a mean time of 52 seconds. The bag was then removed and there ensued a mean duration of 69 seconds of anaesthesia followed by a recovery to being able to stand in a mean time of 125 seconds. I am told the method is still used in Malaya, where it is known as Nunn's Bag!

There is no prize for knowing why most of us have bade farewell to cyclopropane. The violence of the explosion of a mixture of cyclopropane and oxygen can scarcely be imagined by those who have not witnessed a demonstration. Twice, explosions have occurred inside patients in hospitals where I was working. This is not a risk we can still accept.

Nitrous Oxide

The last component of the rotameter block is nitrous oxide — long believed to be weak but harmless. In the last twenty years we have learned that nitrous oxide is not as harmless as once thought. Administration under hyperbaric conditions by teams in Seattle and in the United Kingdom have shown that, under these conditions, nitrous oxide was certainly not the perfect anaesthetic as predicted by Paul Bert. The unpleasant effects experienced by the subjects were probably due to catecholamine release.

Nitrous oxide has a small though definite depressant effect on myocardial contractility. However, in many circumstances this is offset by catecholamine release and systemic vascular resistance is increased, causing blood pressure to be well maintained. At 1.5 MAC, hyperbaric nitrous oxide is a severe respiratory depressant.

However, substitution of 70% nitrous oxide for an equal MAC fraction of a volatile anaesthetic causes an appreciable reduction in Pco_2 in an unstimulated patient or volunteer. This suggests that its respiratory depressant effect is a non-linear function of the MAC-multiple in which it is used. It may be compared with di-ethyl ether which has little effect at one MAC and is a severe depressant at 2 MAC, probably because the effect of catecholamine release predominates at 1 MAC. In this respect nitrous oxide seems advantageous when used during anaesthesia with spontaneous breathing as a component of the carrier gas. It diminishes respiratory depression and, as an added bonus, dollar per MAC/hour, is much the cheapest inhalational anaesthetic.

There can be no doubt that nitrous oxide temporarily increases the size of an air loculus in the body — be it an air embolus, pneumothorax, air in the cerebral ventricles, the middle ear, intestinal contents or "bends" in a diver.

As an anaesthetic, nitrous oxide initially causes arousal and hallucinations as described by Humphry Davy's illustrious subjects in 1800, and likened to LSD by one of my associates familiar with both. It is hardly a typical anaesthetic. Cerebral metabolic rate is slightly increased, but cerebral blood flow is disproportinately increased and intra-cranial pressure may rise.

It is true that the presence of nitrous oxide in the rotameter block has occasionally resulted in the accidental administration of an oxygen-free gas mixture, with potentially lethal consequences. This hazard can be avoided by a mechanical linkage between the oxygen and nitrous oxide flow controls. It should also be detected by the inspired gas monitor. I do not think that this danger should preclude the use of nitrous oxide by properly trained staff.

It has been suggested that the danger of giving nitrous oxide without oxygen could be entirely avoided by dispensing nitrous oxide pre-mixed with 30% oxygen. This attractive idea is entirely feasible. However, once staff had become accustomed to using the mixture, a failure in the system for adding the oxygen could have disastrous consequences, perhaps for many patients. The situation is not comparable to the supply of air instead of nitrogen, because it is hard to see how piped air could lose its oxygen.

The most remarkable adverse effect of nitrous oxide is its interaction with vitamin B12, the coenzyme of methionine synthase, which is inactivated. By changes in a long and complex metabolic chain, there is interference with synthesis of DNA. This seems to be the cause of fetotoxicity (in rodents) and megaloblastosis and leucopenia (in patients). Dr. Eger has pointed out that this appalling catalogue of metabolic misfortune together with other factors would surely stifle any new anaesthetic brought before the FDA but, as Drs. Saidman and Hamilton have said:

> "...except for the complications of chronic use, these effects have not produced a clinical effect recognized by generations of skillful observers." Leucopenia does indeed occur after several days exposure to nitrous oxide.

Megaloblastic marrow is almost always seen after 24 hours and sometimes as soon as 2 hours. However, leucopenia is rare with exposures of 24 hours or less, no doubt owing to stores of mature leucocytes in the bone marrow. On the other hand Amos (1982) drew attention (with tantalizingly few details) to a 90% mortality in 18 megaloblastic patients admitted to Intensive Care after anaesthesia including nitrous oxide — in one case for less than 2 hours. However, these were clinical observations and did not constitute a randomized trial with matched controls.

Whether or not megaloblastosis due to nitrous oxide is really important is unclear at present and will require extensive and very difficult outcome studies. It can, however, be said that the rate of inactivation of B12 in man is much slower than in the rat — the usual experimental subjects. Although the half-time is only 5.4 minutes in the rat, it is 46 minutes in man. Many anaesthetics in the United Kingdom are therefore too short for there to be any effect. I understand this is hardly the case in the USA.

Fetotoxicity of nitrous oxide in the rat was demonstrated by Fink, Shepard and Blandau in 1967. It has since been confirmed beyond any doubt and shown to be absent with xenon and partly reversed by folinic acid. So it appears, at least in part, to be related to inactivation of B12. Happily there is now a large literature which is unanimous in failing to find any fetotoxic effect of nitrous oxide in the human subject. Our own study, the last in this list, agrees with the other studies. If there is an effect, which seems unlikely, then it cannot be important.

In one other area we can also be fairly optimistic. For chronic exposure, the ED_{50} (for rats) is 5,000 ppm and Nick Sharer and I could detect no effect at 450 ppm. There should be not the slightest danger from nitrous oxide in a scavenged operating room and not much risk even without scavenging.

Confusion over epidemiological studies of toxicity in operating theatre personnel is at last resolved. The prospective study of Knill-Jones and Spence covers almost every female doctor in the United Kingdom. It avoids the familiar pitfalls of too few and biased responses and faulty recall. After 9 years of data collection, there is no evidence of increased fetal abnormalities in those who work in operating theatres, and the miniscule increase in miscarriage rate is not statistically significant in the final analysis. If it were real it would be a difference corresponding to the effect of 1-2 cigarettes a day. And this is in a country where scavenging is by no means universal practice.

Only two groups appear to be at risk from chronic exposure to nitrous oxide. Firstly, those who use nitrous oxide for recreational purposes have been known to develop a neurological condition similar to sub-acute combined degeneration of the spinal cord. Secondly, dentists in U.K. who use relative analgesia are exposed to concentrations of nitrous oxide far higher than in operating rooms. Three have been found to have megaloblastic bone marrow. All were exposed to very high concentrations which are never likely to be encountered in operating theatres.

A few weeks ago there was a unanimous vote at the European Academy of Anaesthesiology that nitrous oxide should not be withdrawn. That, however, was not to say that it is the perfect anaesthetic. In most surgical conditions, it is difficult to discern any clear disadvantage in the use of nitrous oxide and elaborate outcome trials will be required. However in certain conditions there are grounds for caution in the use of nitrous oxide because dangerous gas loculi may occur in "bends" and within the cranial cavity. It may also be helpful to avoid nitrous oxide during abdominal surgery. 100% oxygen is mandatory in certain hypoxic conditions and clearly precludes the use of nitrous oxide. The effect on B12 may well contraindicate its use in multi-system failure, in repeated or very prolonged anaesthetics. The case against its use in pregnancy is not substantiated by epidemiological studies. Furthermore, this effect can be offset by large doses of folinic acid.

Dr. Hornbein has admirably summarized the position in his epilogue to Dr. Eger's book on nitrous oxide. Nitrous oxide is not as free from adverse effects as once we thought. He will not throw it out but will recognize its limitations. And so will I. This applies to every drug we use.

In thereapeutics, nothing is completely safe. Everything is relative and risks must always be balanced against benefit. Furthermore risk/benefit ratios themselves are seldom absolute and must be expressed as a probability to individual patients. The gases are no exception to this general rule and balancing the risks with the gases depends on complex considerations. Dr. Rovenstine was no stranger to balancing risks and he would have delighted in the intellectual challenge of new discoveries.

-8-

THE CHANGING HORIZONS IN ANESTHESIOLOGY

by Nicholas M. Greene, M.D.

■ SPECIAL ARTICLE

Anesthesiology
79:164–170, 1993

J. B. Lippincott Company, Philadelphia

The 31st Rovenstine Lecture

The Changing Horizons in Anesthesiology

*Nicholas M. Greene, M.D., F.R.C.Anaesth.**

Modern anesthesiology differs widely from what it was 40–50 years ago, not only because of what anesthesiology now involves in the operating room, but also because anesthesiology has expanded its horizons and activities above and beyond the provision of surgical anesthesia. These changes and the identity of modern anesthesiology are, however, but poorly understood, if understood at all, by the majority of laity and physicians alike. Such lack of identity, especially in the minds of those at the policy- and decision-making level, can only endanger the vitality and future of anesthesiology in an era of sweeping changes in health care-delivery systems. The problem of public identity of our specialty includes the historically correct, but, contemporaneously, all too often misleading name of our specialty. It is suggested that it is appropriate, at this time, to at least consider the potential advantages of changing the name of our specialty to, say, *metesthesiology* and *metesthesiologist,* to indicate that while, today, our specialty continues to involve operative anesthesia, it extends above and beyond to include a wide variety of professional activities outside the operating room richly rewarding to patient and practitioner alike. (Key words: Anesthesiology. History of anesthesia. Metesthesiology.)

ANESTHESIOLOGY has experienced profound changes over the last 40–50 years. There has, however, apparently been no published evaluation of the extent to which things have changed in our specialty, not simply in terms of anesthetic drugs, techniques, or equipment, but, rather, in terms of changes in the horizons, the scope, the vistas—the very composition and definition of anesthesiology. An overview dealing not with individual facets of anesthesiology, but dwelling on the totality of the many changes we have seen, provides the opportunity to consider the progress of anesthesiology as an identifiable intellectual and professional component of modern medical practice. To do so also provides the opportunity to consider some of the problems and challenges in anesthesiology associated with the changes in the specialty that time has wrought.

A useful way to evaluate changes over the last 40–50 years in the horizons of anesthesiology is to compare what anesthesiology consisted of in what can conveniently be referred to as the Rovenstine era—that is, the years in the late 1940s and early to mid-1950s—with the horizons of the specialty in the 1990s. The man honored by this eponymous designation, Dr. Emery A. Rovenstine (1895–1960), was Professor of Anesthesia at New York College of Medicine and Director of the Division of Anesthesia at Belleview Hospital, and one of the giants in anesthesiology during its formative years. What he accomplished and what he represented in New York was also being accomplished, to greater or lesser degrees, by other anesthesiologists outside of New York City. The term Rovenstine era is, thus, used here in a general sense to include not only anesthesiology in New York City, but also in wide areas outside New York. This era is also selected for making comparisons with the present because, starting in 1949, the author, although not in New York, was a participant in, and an observer of, the specialty in that era, as well as the changes that have subsequently taken place.

The Rovenstine Era

Anesthesiology in the Rovenstine era had, when viewed objectively, not horizons: anesthesiology had *a* horizon, a single horizon.[1] That single horizon con-

* Professor of Anesthesiology Emeritus.

Received from the Yale University School of Medicine, New Haven, Connecticut. Accepted for publication March 2, 1993. Based on the author's E.A. Rovenstine Memorial Lecture, presented at the annual meeting of the American Society of Anesthesiologists, New Orleans, Louisiana, October 17–21, 1992.

Address reprint requests to Dr. Greene: Department of Anesthesiology, Yale University School of Medicine, P.O. Box 3333, New Haven, Connecticut 06510.

sisted of the intraoperative care of surgical patients. Surgical—that is, operative—anesthesia constituted about 90% of the professional time and effort of anesthesiologists in that era. There were, of course, anesthesiologists, including Rovenstine,[2] who spent time in the management of patients with chronic pain. There were also anesthesiologists, such as Virginia Apgar,[3] who specialized in obstetric anesthesia. And there were those involved in management of inhalation therapy[4,5] and of blood banks[6] in that era. On average, however, about 90% of the average anesthesiologist's time and effort was spent in the operating room, 40–50 years ago. Research, mostly clinical, was being performed, but the results were easily contained in the two U.S. anesthesia journals of that era, each published bimonthly.

The Present Era

Anesthesiology today offers, in contrast to the past, a variety of professional horizons and intellectual challenges within, and outside, the operating room (table 1). Some are clinical. Some are nonclinical. When, why, and how the areas outside the operating room came to develop as constituents of modern anesthesiology is a tale worthy of more than brief mention here. It deserves a monograph. Just to list these challenges and opportunities, along with a few brief comments, allows one to perceive, however, the degree to which anesthesiology has changed since the 1940s and '50s.

Table 1. Anesthesiology Horizons: 1993

Clinical
Intraoperative
Operating room
Ambulatory surgery
Pharmacologic
Physiologic
Monitoring
Subspecialization
Obstetrical
Chronic pain
Acute pain
Intensive/critical care
Nonclinical
Research
Organizational
Administration
Teaching
Foreign

The *clinical* horizons in anesthesiology today fall into two categories: intraoperative care and management of surgical patients (what we do in the operating room), on the one hand, and, on the other hand, what we do outside the operating room in terms of patient care.

Intraoperative care of surgical patients continues to be a major component of our specialty in 1992. This is necessary and desirable. Intraoperative care of our patients must always remain a major focus of our professional attention. But the intraoperative care of our surgical patients in the operating room has radically changed over the years. One conspicuous change is the locations in which we provide surgical, operative anesthesia. We have seen a proliferation of free-standing and hospital-based ambulatory outpatient surgical centers. The classic operating suite is no longer, by any means, the only place where surgical procedures are being performed.

Not only has the where of operative anesthesia changed; so, too, has the how—the pharmacology—of modern anesthesia. Today, operative anesthesia is based on a level of polypharmacy to an extent and magnitude undreamt of in bygone eras. Indeed, operative anesthesia today may include only homeopathic concentrations of real, true inhalational anesthetics. Indeed, mixtures of intravenous opioids, benzodiazepines, and, of course, neuromuscular relaxants with, perhaps, a bit of nitrous oxide have today become the basis of much general "anesthesia" in many areas. Any consideration of the broadening of our horizons in anesthesiology deserves inclusion of the radical changes in, and the complexity of, the pharmacologic basis of modern operative anesthesia.

The broadening of our horizons within the operating room has not focused entirely on pharmacology. Equal broadening of our horizons in anesthesiology has centered about the physiology of anesthesia, be it general or regional. Aided and abetted by a plethora of sophisticated, complex monitors, invasive and noninvasive, we can today measure intraoperatively almost any physiologic function we want to. Our use of monitors has also extended our horizons, for better or for worse, into a new technical field. We are now expected to be experts in the anatomy, the mechanics, and the function of the monitoring equipment that we rely so much upon.

Still another area in which our horizons in operative anesthesiology have widened in recent years involves ever-increasing subspecialization in management of surgical patients. We still need, and always will need, anesthesiologists best described as generalists. But today we also need (and have, fortunately) anesthesiologists who devote most or all of their attention to cardiac, to pediatric, or to neurosurgical anesthesia, to mention but some of the areas of subspecialization into which anesthesiology has expanded.

Just as our horizons have expanded in operative, surgical anesthesia, so, too, have our horizons today broadened in clinical areas outside the operating room. Especially notable has been the broadening of our horizons to include the field of obstetrics, especially control of pain during labor. The amount of time and energy anesthesiologists today devote to the relief of pain during labor surely represents one of the major areas outside the operating room into which anesthesiology has expanded since the 1940s and '50s.

A second area in which the horizons of anesthesiology have expanded in clinical areas outside the operating room is represented by our ever-increasing and ever-deepening involvement in the management of patients with chronic pain. The number of anesthesiologists today working full- or part-time in pain clinics, and the books and articles they have generated, reflect our growth in this increasingly important area.

A parallel (and long overdue) expansion in our activities has been the introduction by anesthesiologists of patient-controlled analgesic techniques for the management of acute pain, most particularly postoperative pain. This, too, ranks as a major step in the development of modern anesthesiology. As with many of the other changes in our horizons, our involvement in the control of postoperative pain increases the time, effort and energy we spend in patient care outside the operating room.

And then, too, there is the well recognized broadening of the involvement of anesthesiologists in the intensive care of critically ill patients of all ages suffering from all sorts of disorders and disease—another demand on anesthesiologists' time.

Along with the remarkable expansion of the horizons of clinical anesthesiology has been a parallel, and comparable, widening of horizons in nonclinical parts of our specialty. Particularly noteworthy has been the explosive expansion of research. One evidence of our productivity in this field is the geometric increase, an almost overwhelming increase, in the number of anesthesiology research articles being published in an apparently ever-increasing number of anesthesiology journals, certainly a desirable change for the better but not, nevertheless, without problems, too.[7]

A second important area in which we are spending more and more nonclinical time centers about two closely related activities best described under the rubric of organization and administration. These two areas of interest are, in fact, so closely related they can be regarded as one. These types of activities include involvement in intradepartmental and, increasingly, intrainstitutional affairs. More and more we see anesthesiologists assuming positions of authority and responsibility in hospitals, medical schools, and universities. These activities further include the not inconsiderable amount of time spent working in and for the many professional societies to which today's anesthesiologists belong, including national organizations, such as the American Society of Anesthesiologists and its component societies. The value and the importance of the often considerable amount of time spent in areas such as these cannot be underestimated.

Yet another nonclinical area with additional demands on the time and attention of anesthesiologists, especially those in larger, university-affiliated hospitals, is teaching in anesthesiology. Today, teaching ranges from clinical instruction in the operating room, in pain clinics, in critical care areas, to didactic teaching in seminars and to participation in local, regional, national, and international continuing-education programs. Is there any other medical specialty with as many continuing-education program?

Finally, it would be disingenuous were no mention made of the broadening horizon offered to ASA members by the ASA's Overseas Teaching Program in East Africa,[8] a program providing a unique, once-in-a-lifetime opportunity to experience living with, and working professionally with and for, East Africans.

Discussion

Anesthesiology has, indeed, come a long way since the 1940s and '50s. To borrow an analogy, anesthesiology has become a mansion with many rooms, not just one room, operative anesthesia, but with many other rooms for the many other interests and activities that, today, constitute the whole of anesthesiology. By no means, however, are all of the rooms available (table 1) equally occupied in all anesthesiology programs. All anesthesiology departments, by definition, are, of course, involved in the intraoperative management of both surgical and gynecologic patients, be they inpatient, outpatient, or both, as well as obstetric patients having operative deliveries. Anesthesiology departments having only these responsibilities represent one end of the broad spectrum of professional activities found in anesthesiology departments throughout the country. At the opposite end of the spectrum are anesthesiology departments actively involved in all of the many areas listed in table 1.

The spectrum of professional activities of anesthesiologists today can, however, be correlated in a general way (and with notable exceptions) with the size of hospitals as measured by bed capacity. The existence and magnitude of this spectrum of hospitals of different sizes throughout the United States is not widely recognized. Statistical data provided by the American Hospital Association's survey of 5,471 of the acute, general-care hospitals nationally are, however, instructive (table 2).[9] Taking the extremes of hospital sizes, for example, shows that 126,911 (12.9%) of the 982,038 total number of beds in the 5,471 hospitals are found in 2,407 hospitals with less than 100 beds (44.0% of all hospitals). At the opposite end of the bed-capacity spectrum, 222,210 (22.6%) of the 982,038 beds nationally are found in the 330 hospitals with 500 or more beds (6% of all hospitals). In hospitals with less than 100 beds, 2,214,145 operations were annually performed (9.6% of the 23,078,383 operations performed nationally), while 4,959,344 (21.5%) of the operations performed nationally were performed in hospitals with 500 or more beds. Data from hospitals with bed capacities between these two extremes vary widely, with no readily apparent pattern established.

Data on types of operations performed as a function of bed capacity of the hospitals are difficult to obtain. It can be assumed, however, that larger hospitals are more likely to be tertiary care-referral institutions in which more complex, high-risk operations are likely to be performed. So, too, intensive-care programs would be expected to be more frequent, and larger, in larger hospitals. Other nonoperating-room activities, including teaching of medical students and residents, to say nothing of clinical and laboratory research, would, similarly, be expected to be greater in larger hospitals.

Because of the wide variation in the missions of hospitals in the United States, as exemplified by the data in table 2 from 5,471 of them, it is easy to understand why it is possible that individuals associated with but one hospital may not fully appreciate how different the practice of anesthesiology may be in other hospitals, a situation sometimes contributing to difficulty of defining, by practitioners of anesthesiology, exactly what, on a national basis, the specialty consists of.

In listing the roles of anesthesiologists outside the operating room, it should be borne in mind that all anesthesiologists may not share the interest and levels of commitment to innovative programs outside the operating room previously introduced by anesthesiologists who were, at the time, leaders in expanding the specialty beyond the walls of the operating theater. At one time, for example, anesthesiologists in some institutions were, as mentioned above, involved in management of blood banks. Perhaps fortunately enough, this was rather localized and short lived. Anesthesiologists were, more importantly, widely, if not invariably, involved in the early establishment of inhalation or respiratory-therapy departments. Less fortunately, anesthesiologists have, to a considerable degree, retreated from this field, despite their innovative leadership in promotion of such departments. Similarly, although anesthesiologists were pioneers in the development of

Table 2. Hospital Statistics

Bed Capacity	No. of Hospitals	% of All Hospitals	No. of Beds	% of Total No. of Beds	Surgical Operations	% of All Operations
<100	2,407	44.0	126,911	12.9	2,214,145	9.6
100–199	1,320	24.1	187,809	19.1	4,538,097	19.7
200–299	758	13.9	185,057	18.8	4,898,883	21.2
300–399	420	7.7	144,386	14.7	3,818,123	16.5
400–499	238	4.4	105,665	10.8	2,651,811	11.5
≥500	330	6.0	222,210	22.6	4,959,324	21.5
Total	5,473		972,038		23,080,383	

Adapated with permission from the American Hospital Association.[9]

intensive/critical-care units and, although, initially, staffing of these units was primarily by anesthesiologists, anesthesiologists no longer constitute the majority of intensivists. In 1979, 386 (44%) of the 822 physician members of the Society of Critical Care Medicine were anesthesiologists. In 1984, although the number of anesthesiologists in the Society increased to 643, they represented only 27% of the membership. In 1988, the number of anesthesiologists remained essentially unchanged (679), but they constituted only 24% of the membership.[10] The number of anesthesiologists involved in critical care medicine has apparently stabilized, but the number of other physicians in the specialty of critical-care medicine has increased, with the result that anesthesiologists now constitute a minority of physician intensivists. Whether similar changes will occur in chronic-pain clinics and in acute pain-management programs remains to be seen.

That the popularity and attractiveness of some areas into which anesthesiology has expanded may have diminished to some extent does not, however, alter the fact that the horizons of anesthesiology today are substantially greater and more varied than they were in the Rovenstine era. But what has been the effect, the meaning of this widening of our professional activities? As is the case with all changes, one can discern both advantages and disadvantages. The advantages include, without any doubt, improvement in the quality of patient care, both within and outside the operating room. Not only the quality, but the availability of quality patient care has equally increased, a reflection of the increased number of physicians entering anesthesiology. Another important advantage is the expansion of the professional opportunities and intellectual challenges offered today in anesthesiology. There is something for everyone in today's anesthesiology. No longer are our professional and intellectual horizons as restricted to, as focused on, as in the past, almost solely the intraoperative management of our patients. The present openness of the horizons of anesthesiology has undoubtedly contributed, in no small measure, to the influx of physicians into our specialty in recent years, a change good for our patients, for our specialty, and for ourselves.

There are also, however, disadvantages to at least some of the changes our specialty has experienced in recent years. One of these involves loss of contact and rapport with patients associated with the assembly-line processing of early morning admission patients and, often, ambulatory surgical patients. The decrease, or even the elimination, of personal contact and rapport with these patients is a sad commentary on changes in patient care forced upon us in the name of economy and efficiency.

Other disadvantages can be cited, too. None, however, is greater than the discrepancy between what our specialty in reality consists of and what most people, lay people and many, if not most, physicians, think anesthesiology consists of today in 1993. The difference between the widespread, general perception of what anesthesiology in 1993 consists of and what it actually involves can be seen in the difference between perceived and actual allocation of professional time of anesthesiologists. Nonanesthesiologists see anesthesiologists doing nothing aside from being in the operating room all day administering surgical anesthesia. Historically, this was generally quite true. In the Rovenstine era, some 90% of anesthesiologists' time was spent in the operating room. This is no longer the case nationally. Today, there are, indeed, still anesthesiologists who devote 90% of their time to providing operative anesthesia. This is well and good. Desirable and necessary, as it will continue to be. At the other extreme, today, we find anesthesiologists who spend little, if any, time in the operating room. This, too, is well and good. Desirable and necessary for the health and welfare of our patients and our specialty. These latter anesthesiologists might well be spending 90% of their time in clinical practice outside the operating room in areas listed in table 1. In addition, we have the anesthesiologists who spend variable amounts of time devoted to equally important, but nonclinical, activities, especially research, teaching, and administration. An estimate, based upon personal observations and conversations with a large number of anesthesiologists in a wide variety of hospitals across the country, in private practice and in teaching hospitals, is that, today, anesthesiologists spend, *on average,* across the country, somewhere close to 50% of their professional time in operating rooms.

The shift that can be discerned in 1993 in average time spent by anesthesiologists in their classic role in the operating room, a decrease from 90% to about 50%, reflects the change in horizons in anesthesiology that has occurred in the last 40–50 years. The majority of people outside anesthesiology are, however, ignorant of this change. They are ignorant of what modern anesthesiology is all about. The question is, does this lack of understanding about the nature of 20th century *fin de siècle* anesthesiology make any difference? It does. It makes a great deal of difference. The difference is not just one of image alone. It involves matters of considerable substance, as society moves closer and closer to having both practice and delivery dictated by politicians and government agencies working in concert with insurance companies backed up by masses of computer-based data delivered by demographic statisticians. If decision and policy makers, to say nothing of the general public and many (most?) of our medical colleagues, do not understand the breadth of the role and function of modern anesthesiologists, then anesthesiologists will gradually, and increasingly, become isolated from the mainstream of medicine in future years with regression back to activities centered almost entirely within the operating room. Does the aforementioned gradual elution of some anesthesiologists from the very patient services they themselves initiated outside the operating room represent failure of administrators, third-party payers, and others to fully grasp the nature and scope of modern anesthesia, including its organizational, professional, and remunerative status?

Protection of the quality and extent of patient care provided by modern anesthesiologists working within and outside the operating room requires widespread education as to what anesthesiology has become over the years. The most direct, the most effective, even though a somewhat controversial way of defining ourselves and our specialty, must resolve the misunderstanding inherent in the word *anesthesiology* when used to refer to a specialty that includes so many activities and roles above and beyond the historical basis of simply providing operative anesthesia.

Oliver Wendell Holmes was precise, logical, and accurate when he coined the word, *anesthesia,* to describe, in 1846, the condition produced when William Thomas Green Morton gave ether to introduce the world to painless surgery. Holmes synthesized the word *anesthesia* by combining the Greek prefix *an-*, meaning without, with the Greek word for sensation, *esthesia.* Certainly, ether produces total loss of sensation, *i.e.*, anesthesia. But the derivatives of this word, *anesthesiology,* and *anesthesiologist,* are today becoming an ever-more inaccurate and misleading characterization of the true nature of what today's anesthesiologists are involved in. Anesthesiologists have so many more interests, so many more roles, so many more responsibilities than "anesthesia" as classically defined almost 150 years ago.

The time has come, it is suggested, when we should at least consider the virtue of changing the semantics of our specialty as a means for establishing the identity of modern anesthesiology. No word readily comes to mind that might simply, but clearly, indicate that, while intraoperative care of surgical patients is still, and always must be, one of our major interests, it no longer represents the one and only focus of our specialty; nor, often, what we actually do in the operating room. But something should be done to free ourselves from a 150-year-old semantic cul-de-sac that locks us into a perpetual state of misunderstanding about our specialty. The best way to solve our identity problem seems to lie in the generation of a new word to describe our specialty. One way of doing this, although other descriptive terms might be equally, if not more, appropriate, is to create a new word by replacing the prefix *an-* (without) with another Greek prefix that carries with it, among other connotations, a sense of above, beyond, or more than. This prefix is *met-*. Retaining the base *esthesia* and combining it with the new prefix, *met-*, we have *metesthesia,* that is, above and beyond *esthesia* (sensation) as in combinations such as metaanalysis, metacarpal, metaphysical, metaphor, etc. *Metesthesiology* and *metesthesiologist* are terms indicative of the fact that our specialty, while still concerned about sensation, especially pain, transcends our focus on intraoperative pain to include a collection of separate, though related, interests, skills, and obligations. Such a change in name more accurately describes what we do. Such a change in name is bold enough and conspicuous enough to be more effective in clarifying our identity than the changes from *anaesthesia* to *anesthesia* to *anesthesiology* introduced in the past for the same purpose. Metesthesiology and metesthesiologist will emphasize to patients, to physicians, and to insurance companies and government and other nongovernment third-party payers that members of our specialty are trained to do more than administer anesthetics and that activities outside the operating room are as worthy of attention (and compensation) as is administration of an anesthetic in the operating room. Current historically important organizations and publications may well, and justifiably, elect to use the older term, but Departments of Anesthesiology, to say nothing of Departments of Anesthesiology, Pain Management, and Intensive Critical Care, might welcome the clarity and simplicity inherent in the term Department of Metesthesiology. Certainly, the suggested change in name will, more importantly, rapidly cause one and all to realize that, yes, our specialty has changed and advanced, not only from the Morton era of 150 years ago, but also from the Rovenstine era 40–50 years ago, a fact many still do not comprehend.

References

1. Greene NM: Anesthesiology and the University. Philadelphia, J.B. Lippincott Company, 1975, pp 38–68
2. Rovenstine EA, Hershey SG: Therapeutic and diagnostic nerve blocking: A plan for organization. ANESTHESIOLOGY 5:574–582, 1944
3. Apgar V: A proposal for a new method of evaluation of the newborn infant. Anesth Analg 32:260–267, 1953
4. Ryder HW, Kehoe RA: Rationale and hazards of pressure breathing and oxygen therapy. ANESTHESIOLOGY 9:21–31, 1948
5. Christensen EM, Urry AG, Cullen SC: Alveolar and arterial oxygen contents during oropharyngeal oxygen therapy. ANESTHESIOLOGY 7:399–406, 1946
6. Lundy JS, et al: Annual report for 1951 Section of Anesthesiology, including data and remarks concerning blood transfusion and use of plasma substitutes. Mayo Clinic Proceed Staff Meetings 27:525–526, 1952
7. Greene NM: Anesthesiology journals, 1992. Anesth Analg 74: 116–120, 1992
8. Greene NM: Anesthesia in underdeveloped countries: A teaching program. Yale J Biol Med 64:403–407, 1991
9. Hospital Statistics, 1992–93 Edition. American Hospital Association, Chicago, 1993, p 8
10. Kirby RR: Overview of anesthesiology and critical care medicine, Anesthesia, 3rd edition. Edited by Miller RD. New York. Churchill-Livingston, 1990, pp 2149–2168

Wood Library-Museum of Anesthesiology, 1994