

Arterial Pressure: Long-term Regulation

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Control of blood pressure is a complex event. Control of rapid changes in blood pressure resides in the autonomic nervous system;^{2,3,10,11,12,13} however, the nervous system mechanisms become increasingly ineffective over the long term. When considering arterial pressure over a lengthy period of time, attention must shift to the kidneys and their role in arterial pressure regulation.^{3,4,7,8} This article will provide an introduction to the renal-body fluid system and its effect on arterial pressure.

PRESSURE DIURESIS EXPLAINED

The renal-body fluid system is conceptually easy to understand. The relationship between extracellular fluid and arterial pressure can be explained simply. Greater than normal amounts of extracellular fluid cause a rise in arterial pressure. The rise in arterial pressure causes the kidneys to excrete greater amounts of fluid, a process called pressure diuresis, thereby reducing the amount of extracellular fluid and returning the arterial pressure to the normal range.¹ To illustrate the relationship between arterial pressure and renal function, Figure 1 shows three points on a continuum. At 50 millimeters of mercury (mm Hg) of arterial pressure, the kidneys produce essentially no urine. At 100 mm Hg of arterial pressure, urinary output is normal. At 200 mm Hg, a doubling of arterial pressure, urinary output is increased by six to eightfold. Several points should be clear. First, the range of correction available for low pressure is relatively narrow, between 100 mm Hg and 50 mm Hg. With a loss of 50 mm Hg arterial pressure, urine output falls to 0. On the other hand, increases in arterial pressure range to 200 mm Hg with a potential eightfold increase in output.

This difference should make sense from an evolutionary and survival perspective. A significant decrease in blood pressure can kill quickly. Excepting an attendant, cerebral vascular accident, high blood pressure tends to cause damage over a period of time. In hypovolemic shock, it is critically important

to replace fluids, and the easiest way is to stop excretion of water. In this article, however, we will be considering the factors related to a chronic increase in blood pressure. In a closely related phenomenon, the same process holds true for sodium output, called pressure natriuresis. Any correction in arterial pressure is limited by the rate of urinary output. Corrections in this system are spread out over a given period of time and are not instantaneous.^{3,4,7,8}

UNDERSTANDING THE RENAL OUTPUT CURVE

While the concept of pressure diuresis is easy to understand, the details are more complicated. To understand relationships properly, pay careful attention to the renal output curve (Figure 1). Notice that a horizontal line (blue) drawn across the chart at the level of normal urinary input and output (indicated by the number one on the left hand side of the chart) intersects the curving line at an arterial pressure of 100 mm Hg. This horizontal line represents the intake of water and salt minus the water and salt lost by means other than urinary output. Water and salt lost by other means must be subtracted from total intake so intake can be compared with output related to renal function alone. In reality, all intake and output must be calculated, but in order to examine renal function alone, the adjustment for water and salt lost through other mechanisms must be calculated.

For a healthy and balanced system, the intake of water and salt must equal the output of these substances over a period of time. The point at which these occur is the point of intersection of the intake and output line with the arterial pressure curve. This is the point of equilibrium, and it directly correlates to an arterial pressure of 100 mm Hg.⁵ Since this is the point of equilibrium at which water and salt intake and output are balanced, the system will seek to return to this point given any variance from the norm.^{3,4,7,8}

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Notice that a doubling of arterial pressure to 200 mm Hg results in approximately a sevenfold increase in urinary output; a 50 percent change in arterial pressure from 100 mm Hg to 150 mm Hg results in approximately a threefold increase in urinary output; and a 25 percent change results in approximately a doubling of urinary output. Since the renal output curve is a continuum, even a 1 mm Hg increase in arterial pressure results in an increase in urinary output. The renal output curve is relatively steep, and a small percentage of pressure change results in a disproportionately large change in renal output. As the body loses fluid, blood volume decreases. The decrease in blood volume lowers arterial pressure. The process will continue until the point of equilibrium is re-established.

The opposite is true when arterial pressure falls. At 75 mm Hg renal output is less than half that of intake. As the body gains fluid, blood volume increases. The increase in blood volume raises the arterial pressure. The process continues until the point of equilibrium is re-established. Because the system is a continuum, it is always active. As long as the kidneys are capable of functioning properly, this process will seek to return the arterial pressure to 100 mm Hg.

THE INFINITE GAIN PRINCIPLE

The mechanism that returns arterial pressure to the point of equilibrium is called the infinite gain principle. Given the stable and precise relationship between intake and output illustrated in Figure 1, the mean arterial pressure will remain 100 mm Hg. However, long-term physiologic changes do occur.

There are two ways in which mean arterial pressure point of equilibrium can be shifted from the point of 100 mm Hg: (1) change the renal output curve and (2) change the water and salt intake curve.

If some abnormality in the kidney causes the renal output curve to shift to the right by 50 mm Hg so that the level of output is at 0 and arterial pressure is 100 mm Hg

(instead of 50 mm Hg as previously illustrated), the new point of equilibrium becomes 150 mm Hg or 50 mm Hg above the norm. In this case, intake remained constant but the renal output curve shifted to the right resulting in a 50 mm Hg increase in the equilibrium point. On the other hand, the renal output curve can remain constant, but an increase in water and salt intake drives up the point of equilibrium. A threefold rise in intake drives the point of equilibrium to 150 mm Hg.

It is relatively difficult to change the long-term equilibrium point. It can only be changed by a shift in the renal output curve or the water and salt intake level. If one of these changes is achieved, however, a long-term shift in the point of equilibrium will result, and mean arterial pressure will be regulated by normal means to the new point of equilibrium.^{3,4,5,7,8} If the shift is to the right, it represents a pathologic condition called chronic hypertension.

As indicated in the first paragraph of this article, short-term responses to arterial pressure changes are under the control of the central nervous system. However, the normal equation for arterial pressure is arterial pressure equals cardiac output multiplied by total peripheral resistance. When peripheral resistance increases, arterial pressure increases.^{3,9} This is always true in the acute case; yet, we know clinically that when the kidneys continue to function normally, arterial pressure returns to normal.

As long as the peripheral resistance within the kidneys themselves is not increased, the normal diuretic and natriuretic activity of the kidneys will act to return the arterial pressure to the equilibrium point. So, a consistent clinical principle is at play. As long as kidney function, diuresis and natriuresis is normal, arterial pres-

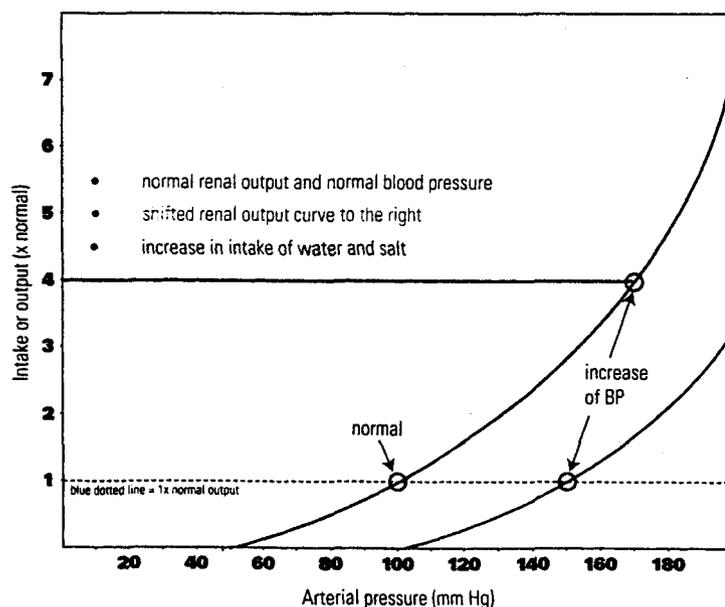


FIGURE 1

sure will return to the equilibrium point over the long term. However, if the peripheral resistance within the kidneys is increased, kidney function itself is affected. Over a period of time, the renal output curve is pushed to the right, and the equilibrium point is moved to a higher point resulting in a chronic increase in arterial pressure.⁷ This response may result from vasoconstrictor mechanisms^{8,9} or a long-term increase in extracellular fluid.

CONCLUSION

This article is concerned only with the mechanism involved in long-term increase of extracellular fluid. The increase in extracellular fluid results in an increase in blood volume. This increase in volume means that capillaries have a greater filling pressure. An increase on the arterial size causes an increase in venous return. The increased blood returned to the heart results in increased cardiac output. Since arterial pressure is a function of cardiac output times peripheral resistance, the increase in output directly causes an increase in arterial pressure. However, the increased cardiac output can cause an increase in arterial pressure through a secondary means. Another automatic mechanism exists within tissue to help regulate blood flow. When blood flow increases in tissue, a constriction of the vessels takes place. This is called autoregulation. It serves the same purpose as the equilibrium point discussed above, to return the system it regulates to normal. Since an increase in cardiac output affects blood flow through all tissues, the autoregulatory mechanism will cause vasoconstriction in all tissues. This increases total peripheral resistance, which increases arterial pressure.^{3,6,7}

For all its potential effects, increases in extracellular water are not as problematic as increases in salt, because water is excreted relatively easily while salt is more difficult to remove. The effects of increased salt are two. Stimulation of the thirst center drives an increase in the intake of water and stimulates the hypothalamic and posterior pituitary mechanism that secretes antidiuretic hormone. Increased intake directly increases extracellular fluid. Antidiuretic hormone causes the kidneys to reabsorb water in the renal tubules causing an increase in extracellular fluid. The increase in extracellular fluid recreates the phenomenon discussed above.^{1,14,15,16,17}

In summary, this article has reviewed the relationship between the renal-body fluid system and arterial pressure. When the equilibrium point is pushed to the right, chronic hypertension results. Chronic increases in arterial pressure are

related to increased morbidity and mortality. Regulation of blood pressure is essential to healthy living. 

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