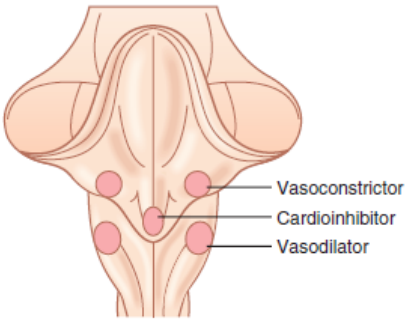
Nervous Regulation of the Circulation and Rapid Control of Arterial Pressure

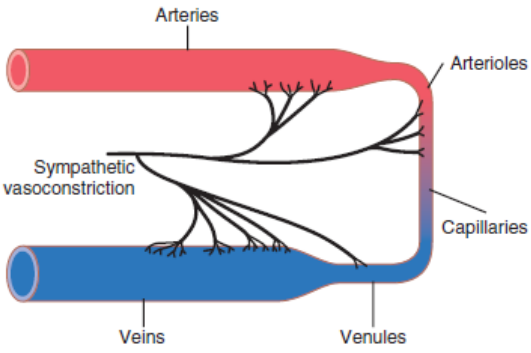
Sympathetic Innervations of the Blood Vessels

Figure below shows distribution of sympathetic nerve fibers to the blood vessels, demonstrating that in most tissues all the vessels *except* the capillaries are innervated. Precapillary sphincters and met arterioles are innervated in some tissues, such as the mesenteric blood vessels, although their sympathetic innervations is usually not as dense as in the small arteries, arterioles, and veins.

The innervations of the *small arteries* and *arterioles* allows sympathetic stimulation to increase *resistance* to blood flow and thereby *decrease* the rate of blood flow through the tissues.

The innervations of the large vessels, particularly of the *veins*, makes it possible for sympathetic stimulation to *decrease* the volume of these vessels. This decrease in volume can push blood into the heart and thereby plays a major role in regulation of heart pumping.





Sympathetic Stimulation Increases Heart Rate and Contractility. Sympathetic fibers also go directly to the heart. It should be recalled that sympathetic stimulation markedly increases the activity of the heart, both increasing the heart rate and enhancing its strength and volume of pumping.

Parasympathetic Stimulation Decreases Heart Rate and Contractility. Although the parasympathetic nervous system is exceedingly important for many other autonomic functions of the body, such as control of

multiple gastrointestinal actions, it plays only a minor role in regulating vascular function in most tissues. Its most important circulatory effect is to control heart rate by way of *parasympathetic nerve fibers* to the heart in the *vagus nerves*, from the brain medulla directly to the heart. parasympathetic stimulation causes a marked *decrease* in heart rate and a slight decrease in heart muscle contractility.

Sympathetic Vasoconstrictor System and Its Control by the Central Nervous System

The sympathetic nerves carry tremendous numbers of *vasoconstrictor nerve fibers* and only a few vasodilator fibers. The vasoconstrictor fibers are distributed to essentially all segments of the circulation, but more to some tissues than to others. This sympathetic vasoconstrictor effect is especially powerful in the kidneys, intestines, spleen, and skin but is much less potent in skeletal muscle and the brain.

Continuous Partial Constriction of the Blood Vessels Is Normally Caused by Sympathetic Vasoconstrictor Tone. Under normal conditions, the vasoconstrictor area of the vasomotor center transmits signals continuously to the sympathetic vasoconstrictor nerve fibers over the entire body, causing slow firing of these fibers at a rate of about one half to two impulses per second. This continual firing is called *sympathetic vasoconstrictor tone.* These impulses normally maintain a partial state of contraction in the blood vessels, called *vasomotor tone*.

Control of Heart Activity by the Vasomotor Center. At the same time that the vasomotor center(in the medulla oblongata) regulates the amount of vascular constriction, it also controls heart activity. The *lateral* portions of the vasomotor center transmit excitatory impulses through the sympathetic nerve fibers to the heart when there is a need to increase heart rate and contractility. Conversely, when there is a need to decrease heart pumping, the *medial* portion of the vasomotor center sends signals to the adjacent *dorsal motor nuclei of the vagus nerves*, which then transmit parasympathetic impulses through the vagus nerves to the heart to decrease heart rate and heart contractility. Therefore, the vasomotor center can either increase or decrease heart activity.

Heart rate and strength of heart contraction ordinarily increase when vasoconstriction occurs and ordinarily decrease when vasoconstriction is inhibited.

Role of the Nervous System in Rapid Control of Arterial Pressure

One of the most important functions of nervous control of the circulation is its capability to cause rapid increases in arterial pressure. For this purpose, the entire vasoconstrictor and cardioaccelerator functions of the sympathetic nervous system are stimulated together. At the same time, there is reciprocal inhibition of parasympathetic vagal inhibitory signals to the heart. Thus, the following three major changes occur simultaneously, each of which helps to increase arterial pressure:

1. *Most arterioles of the systemic circulation are constricted*, which greatly increases the total peripheral resistance, thereby increasing the arterial pressure.

2. *The veins especially (but the other large vessels of the circulation as well) are strongly constricted.* This constriction displaces blood out of the large peripheral blood vessels toward the heart, thus increasing the volume of blood in the heart chambers. The stretch of the heart then causes the heart to beat with far greater force and therefore to pump increased quantities of blood. This also increases the arterial pressure.

3. Finally, *the heart is directly stimulated by the autonomic nervous system, further enhancing cardiac pumping.* Much of this enhanced cardiac pumping is caused by an increase in the heart rate, which sometimes increases to as much as three times normal. In addition, sympathetic nervous signals have a significant direct effect to increase contractile force of the heart muscle, increasing the capability of the heart to pump larger volumes of blood. During strong sympathetic stimulation, the heart can pump about two times as much blood as under normal conditions, which contributes still more to the acute rise in arterial pressure.

INCREASES IN ARTERIAL PRESSURE DURING MUSCLE EXERCISE AND OTHER TYPES OF STRESS

An important example of the nervous system's ability to increase arterial pressure is the rise in pressure that occurs during muscle exercise. During heavy exercise, the muscles require greatly increased blood flow. Part of this increase results from local vasodilation of the muscle vasculature caused by increased metabolism of the muscle cells. An additional increase results from simultaneous elevation of arterial pressure caused by sympathetic stimulation of the overall circulation during exercise. In heavy exercise, the arterial pressure rises about 30 to 40 percent, which increases blood flow almost an additional twofold.

The increase in arterial pressure during exercise results mainly from effects of the nervous system. At the same time that the motor areas of the brain become activated to cause exercise, most of the reticular activating system of the brain stem is also activated, which includes greatly increased stimulation of the vasoconstrictor and cardioacceleratory areas of the vasomotor center. These effects increase the arterial pressure instantaneously to keep pace with the increase in muscle activity.

In many other types of stress besides muscle exercise, a similar rise in pressure can also occur. For instance, during extreme fright, the arterial pressure sometimes rises by as much as 75 to 100 mm Hg within a few seconds. This response is called the *alarm reaction*, and it provides an excess of arterial pressure that can immediately supply blood to the muscles of the body that might need to respond instantly to enable flight from danger.

Baroreceptor Arterial Pressure Control System—Baroreceptor Reflexes

By far the best known of the nervous mechanisms for arterial pressure control is the *baroreceptor reflex.* Basically, this reflex is initiated by

stretch receptors, called either *baroreceptors* or *pressoreceptors*, located at specific points in the walls of several large systemic arteries. A rise in arterial pressure stretches the baroreceptors and causes them to transmit signals into the CNS. “Feedback” signals are then sent back through the autonomic nervous system to the circulation to reduce arterial pressure downward toward the normal level.

After the baroreceptor signals have entered the nucleus of the medulla, secondary signals *inhibit the vasoconstrictor center* of the medulla and *excite the vagal parasympathetic center.* The net effects are

(1) *vasodilation* of the veins and arterioles throughout the peripheral circulatory system and

(2) *decreased heart rate* and *strength of heart contraction.*

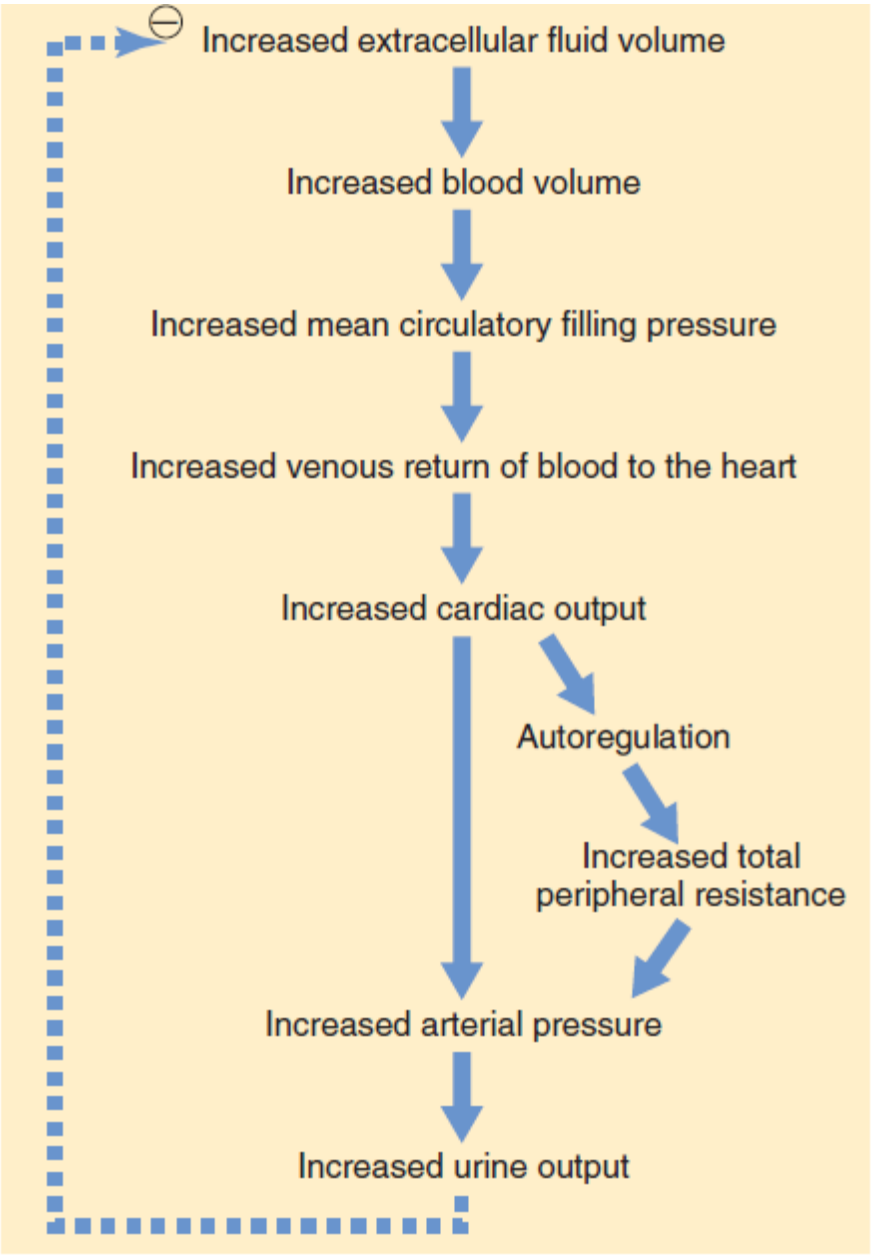
Therefore, excitation of the baroreceptors by high pressure in the arteries reflexly *causes the arterial pressure to decrease* because of both a decrease in peripheral resistance and a decrease in cardiac output. Conversely, low pressure has opposite effects, reflexly causing the pressure to rise back toward normal.

Role of kidney in control of arterial pressure

The sympathetic nervous system plays a major role in short-term arterial blood pressure regulation primarily through the effects of the nervous system on total peripheral vascular resistance and capacitance, as well as on cardiac pumping ability, The body, however, also has powerful mechanisms for regulating arterial pressure week after week and month after month. This long-term control of arterial pressure is closely intertwined with homeostasis of body fluid volume, which is determined by the balance between the fluid intake and output. For long-term survival, fluid intake and output must be precisely balanced, a task that is performed by multiple nervous and hormonal controls and by local

control systems within the kidneys that regulate their excretion of salt and water.

The renal–body fluid system for arterial pressure control acts slowly but powerfully as follows: If blood volume increases and vascular capacitance is not altered, arterial pressure will also increase. The rising pressure, in turn, causes the kidneys to excrete the excess volume, thus returning the pressure back toward normal. an increase in arterial pressure in the human of only a few mm Hg can double renal output of water, a phenomenon called *pressure diuresis,* as well as double the output of salt, which is called *pressure natriuresis.*



Importance of Salt (NaCl) in the Renal–Body Fluid for Arterial Pressure Regulation

Although the discussions thus far have emphasized the importance of volume in regulation of arterial pressure, an increase in salt intake is far more likely to elevate the arterial pressure than is an increase in water intake. The reason for this finding is that pure water is normally excreted by the kidneys almost as rapidly as it is ingested, but salt is not excreted so easily. As salt accumulates in the body, it also indirectly increases the extracellular fluid volume for two basic reasons:

1. When there is excess salt in the extracellular fluid, the osmolality of the fluid increases, which in turn stimulates the thirst center in the brain, making the person drink extra amounts of water to return the extracellular salt concentration to normal. This increases the extracellular fluid volume.

2. The increase in osmolality caused by the excess salt in the extracellular fluid also stimulates the hypothalamic-posterior pituitary gland secretory mechanism to secrete increased quantities of *antidiuretic hormone(aldosterone)*. The antidiuretic hormone then causes the kidneys to reabsorb greatly increased quantities of water from the renal tubular fluid, thereby diminishing the excreted volume of urine but increasing the extracellular fluid volume.

Thus, for these important reasons, the amount of salt that accumulates in the body is the main determinant of the extracellular fluid volume. Because only small increases in extracellular fluid and blood volume can often increase the arterial pressure greatly if the vascular capacity is not simultaneously increased, accumulation of even a small amount of extra salt in the body can lead to considerable elevation of arterial pressure. This is only true, however, if the excess salt accumulation leads to an increase in blood volume and if vascular capacity is not simultaneously increased. raising salt intake in the absence of impaired kidney function or excessive formation of antinatriuretic hormones usually does not increase arterial pressure much because the kidneys rapidly eliminate the excess salt and blood volume is hardly altered.

Renin –Angiotensin system in kidney and its role in control arterial pressure

Aside from the capability of the kidneys to control arterial pressure through changes in extracellular fluid volume, the kidneys also have another powerful mechanism for controlling pressure: the renin-angiotensin system.

Renin is a protein enzyme released by the kidneys when the arterial pressure falls too low. In turn, it raises the arterial pressure in several ways, thus helping to correct the initial fall in pressure.

the functional steps by which the renin-angiotensin system helps to regulate arterial pressure.

Renin is synthesized and stored in an inactive form called *prorenin* in the *juxtaglomerular cells* (JG cells) of the kidneys. The JG cells are modified smooth muscle cells located mainly *in the walls of the afferent arterioles immediately proximal to the glomeruli*. When the arterial pressure falls, intrinsic reactions in the kidneys cause many of the prorenin molecules in the JG cells to split and release renin. Most of the renin enters the renal blood and then passes out of the kidneys to circulate throughout the entire body. However, small amounts of the renin do remain in the local fluids of the kidney and initiate several intrarenal functions.

Renin itself is an enzyme, not a vasoactive substance, renin acts enzymatically on another plasma protein, a globulin called *renin substrate* (or *angiotensinogen*), to release a 10-amino acid peptide, *angiotensin I*. Angiotensin I has mild vasoconstrictor properties but not enough to cause significant changes in circulatory function. The renin persists in the blood for 30 minutes to 1 hour and continues to cause formation of still more angiotensin I during this entire time.

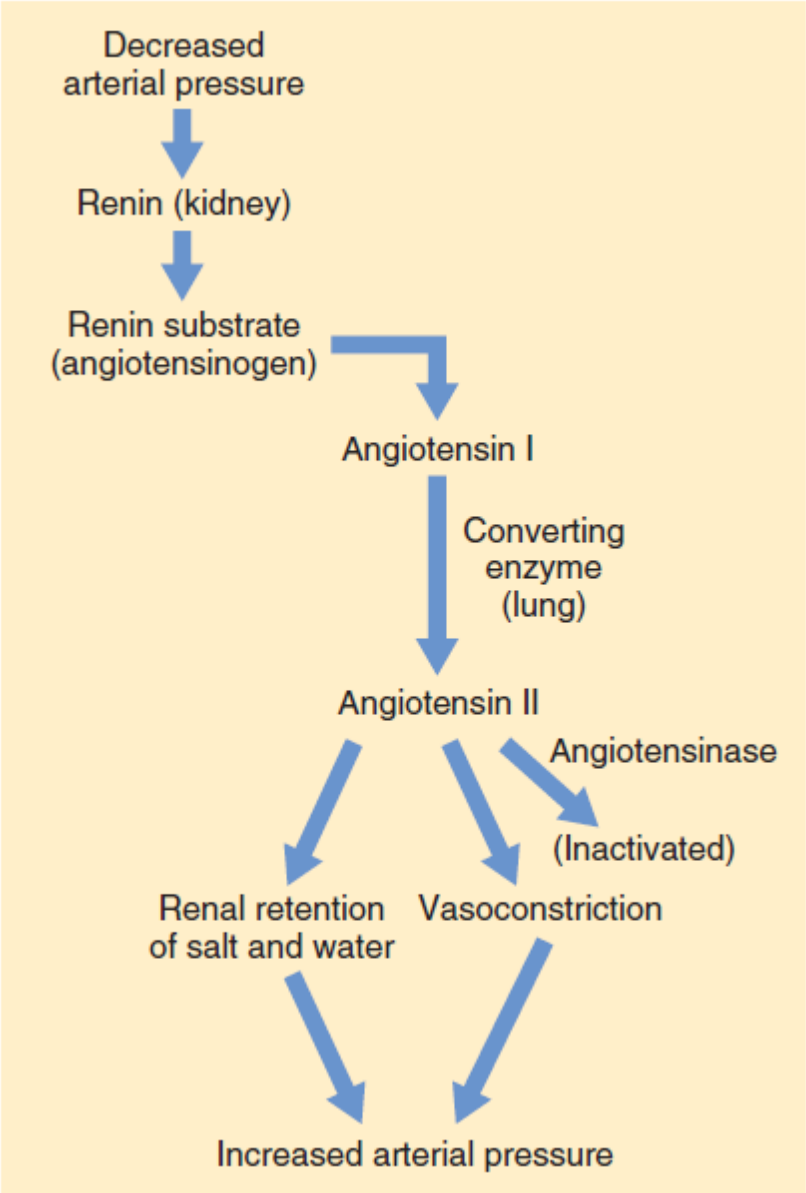
Within a few seconds to minutes after formation of angiotensin I, two additional amino acids are split from the angiotensin I to form the 8-amino acid peptide *angiotensin II*. This conversion occurs to a great extent in the lungs while the blood flows through the small vessels of the lungs, catalyzed by an enzyme called *angiotensin-converting enzyme*

that is present in the endothelium of the lung vessels. Other tissues such as the kidneys and blood vessels also contain converting enzyme and therefore form angiotensin II locally.

Angiotensin II is an extremely powerful vasoconstrictor, and it affects circulatory function in other ways as well. However, it persists in the blood only for 1 or 2 minutes because it is rapidly inactivated by multiple blood and tissue enzymes collectively called *angiotensinases*.

Angiotensin II has two principal effects that can elevate arterial pressure. The first of these, *vasoconstriction in many areas of the body,* occurs rapidly. Vasoconstriction occurs intensely in the arterioles and much less so in the veins. Constriction of the arterioles increases the total peripheral resistance, thereby raising the arterial pressure. Also, the mild constriction of the veins promotes increased venous return of blood to the heart, thereby helping the heart pump against the increasing pressure.

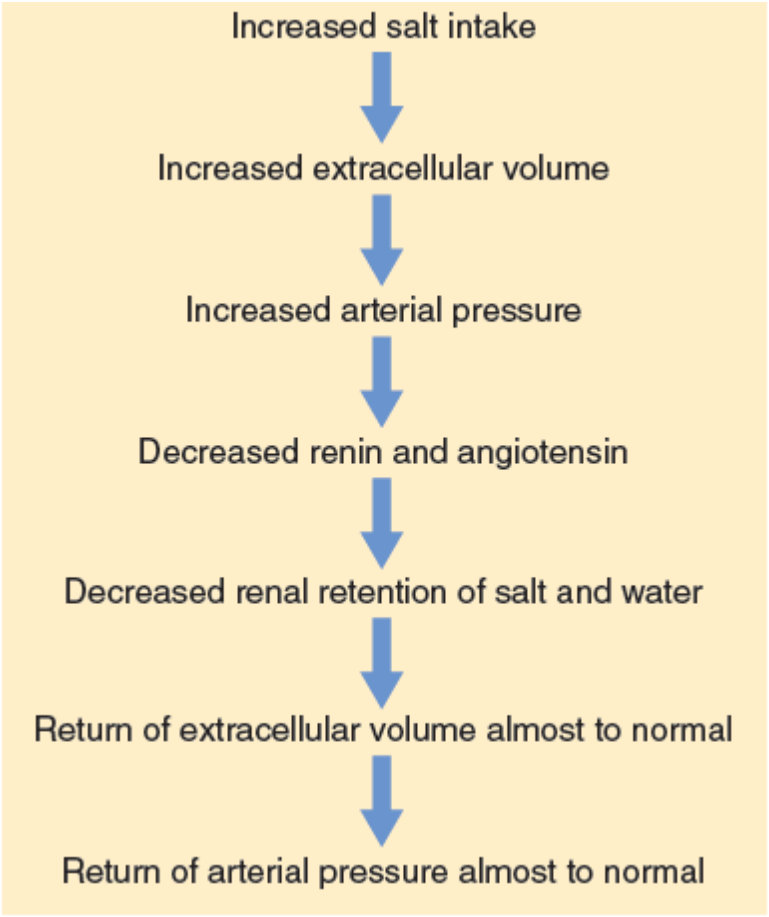
The second principal means by which angiotensin II increases the arterial pressure is to *decrease excretion of both salt and water* by the kidneys. Increases the extracellular fluid volume which then increases the arterial pressure during subsequent hours and days. This long-term effect, acting through the extracellular fluid volume mechanism, is even more powerful than the acute vasoconstrictor mechanism in eventually raising the arterial pressure .



Angiotensin II causes the kidneys to retain both salt and water in two major ways:

1. Angiotensin II acts directly on the kidneys to cause salt and water retention.

2. Angiotensin II causes the adrenal glands to secrete aldosterone, and the aldosterone in turn increases salt and water reabsorption by the kidney tubules Thus, whenever excess amounts of angiotensin II circulate in the blood, the entire long-term renal–body fluid mechanism for arterial pressure control automatically becomes set to a higher arterial pressure level than normal.


Increased salt intake
Increased extracellular volume
Increased arterial pressure
Decreased renin and angiotensin
Decreased renal retention of salt and water
Return of extracellular volume almost to normal
Return of arterial pressure almost to normal