Neurological and humoral control of blood pressure

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Abstract

There is a relationship between arterial blood pressure, cardiac output and vascular resistance which can be described mathematically, and helps us to understand the short-term control of blood pressure in the terms of a hydraulic system. The sensors in this system are the arterial baroreceptors which mediate changes in the hydraulic system through control of the autonomic nervous system, which in turn influences heart rate, inotropy and vascular tone. Altering the distribution of blood between the arterial and venous systems compensates for acute changes in total blood volume. The total blood volume is controlled predominantly by the kidney, with the renin–angiotensin–aldosterone system acting as both the 'sensor' of blood pressure/volume (via renin release in the juxtaglomerular apparatus) and the 'effector' of blood pressure/volume (via aldosterone secretion by the adrenal cortex). Overall control is shared; the baroreceptors being responsible for mediating short-term changes, and renal mechanisms determining the long-term control of blood pressure. These systems have to be adaptable in order to deal with physiological variation in the delivery of blood to tissues from rest to exercise, and with the large shifts in blood volume seen in acute haemorrhage. Pathophysiological changes in these systems lead to maladaptive responses, with systemic hypertension the most commonly seen.

Keywords Baroreceptor reflex; blood pressure; cardiac output; diuresis; haemorrhage; hypertension; natriuresis; renin–angiotensin–aldosterone system; vascular resistance

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Introduction

Systemic blood pressure, the cardiac output and circulating blood volume determine the tissue blood flow and as such the function of organ system. Regional flow is governed by the pressure generated by the heart and the resistance to flow exerted by the blood vessels supplying that region. In order to maintain adequate blood supply to individual organs, a system of feedback loops regulate the blood pressure on a short-term (i.e. beat-to-beat) and long-term basis.

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Learning objectives

After reading this article you should understand:

- how arterial blood pressure is controlled by the baroreceptor reflex
- the sensory, transduction and effector systems in the baroreceptor reflex
- how vascular parameters (pressure, flow, radius, blood volume) are combined to create a hydraulic model of blood pressure
- how the kidney contributes to blood pressure control
- pressure natriuresis and diuresis as mechanisms that control blood volume

Blood pressure

Grodins derived a number of equations to describe the flow through blood vessels.[1] These have become the standard by which acute blood pressure, circulating volume and vascular resistance are understood. Flow is proportional to the pressure gradient across a vessel, and indirectly proportional to its resistance. Expressed simply for the whole circulation[2]:

$$\text{Cardiac output} = (\mathbf{Pa} - \mathbf{Pv})/\mathbf{R}$$
$$V = Va + Vv$$
$$Pa = Va/Ca$$
$$Pv = Vv/Cv$$

Pa = arterial pressure, Pv = venous pressure, R = total peripheral resistance, V = total blood volume, Va = arterial blood volume, Vv = venous blood volume, Ca = arterial compliance, Cv = venous compliance. Where = heart rate × stroke volume, and R α vessel radius^{-4}.

This model represents a hydraulic model of blood pressure control and versions are often used in reference to the treatment of hypertension.[3] It assumes a fixed total blood volume, and is thus a 'closed' system. This is useful in understand what happens to blood pressure acutely, for instance with pathological vasodilation. These equations contain only vascular factors, but over longer periods of time feedback systems allow total blood volume to be controlled independently of these. Total blood volume then becomes a balance between intake and excretion of fluid and is regulated by the kidney.

The mean systemic arterial pressure decreases from the aorta at 100 mmHg to 35 mmHg at the level of the arteriole, whereas mean systemic venous pressure is 3–8 mmHg (Figure 1). The arterial and venous pressures in the pulmonary circulation are about one-fifth of systemic values.

The arterial system comprises the resistance vessels. By varying the smooth muscle tone in their walls vasoconstriction and vasodilation can occur, with a direct and immediate effect on total peripheral resistance. Changes in their calibre results in alteration of perfusion pressure across tissue beds and the flow rate through these vessels. By varying the arteriolar radius in different tissue beds (and whole circulations), the pressure and flow to those organs can be managed independently, allowing a variety of operating flows at rest and exercise. In contrast, the venous system comprises the capacitance vessels. They contain

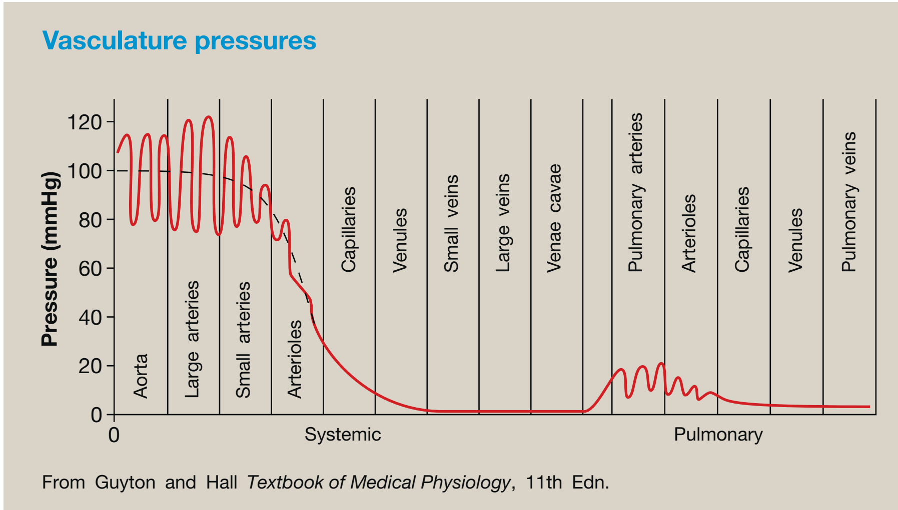

Figure 1

70—80% of the blood volume, so venoconstriction or venodilation will influence this volume distribution (and will transiently alter venous return and stroke volume), but has little effect on total peripheral resistance.

Systemic arterial pressure is what is usually measured and treated in clinical practice. There is a large variation in mean arterial blood pressure with activity levels and wakefulness, with age, gender and ethnicity. As such, a population average is of little clinical use. A desirable blood pressure is said to be 115/75 mmHg,[4] a risk of cardiovascular disease is observed to progressively increase above these values. Hypertension is suspected based on a clinic-measured blood pressure of 140/90 mmHg or higher, though can only be confirmed with ambulatory or home blood pressure measuring 135/85 mmHg or higher.[5] Hypotension is only of clinical relevance when symptoms occur.

Neurological control of blood pressure

Arterial baroreceptor reflex

The baroreceptor reflex (Figure 2) is the predominant control mechanism of short-term blood pressure. It is a negative feedback loop, mediated by the specialized pressure sensors situated in the carotid sinuses, in the aortic arch and at the bifurcation of the internal and external carotid arteries. These mechanoreceptors are spray-type nerve endings, situated in blood vessel walls which respond to both circumferential and longitudinal stretch.

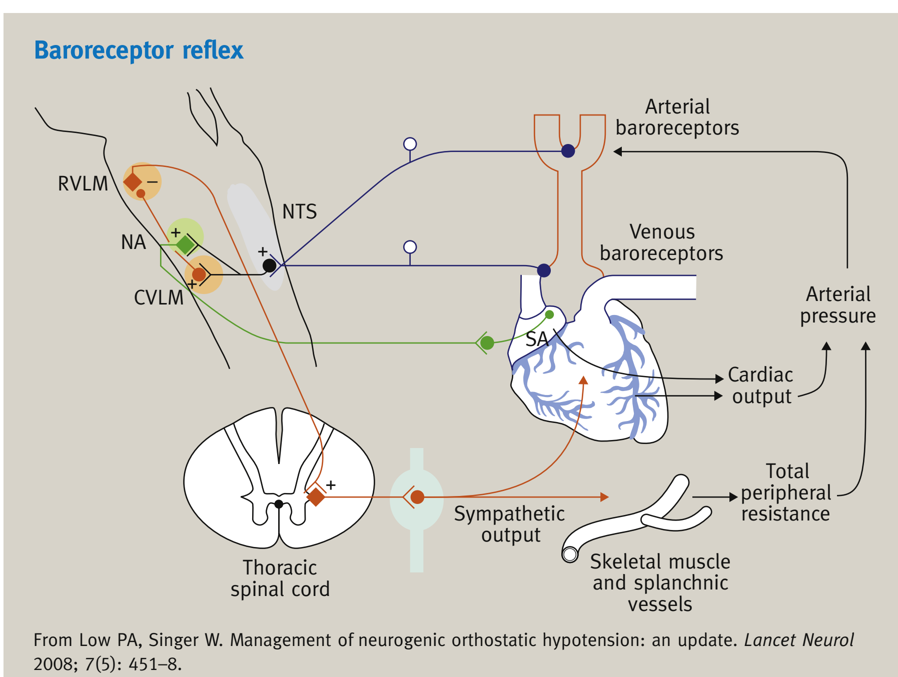

Figure 2