Parameter Sensitivity Analysis of a Network Model of Systemic Circulatory Mechanics

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A previous analytical model of the systemic circulatory system (Grodins, Quarterly Review of Biology, 1959, 34, 93-116) was extended based on recent experimental studies. Major units considered are: large arteries, large veins, and the peripheral circulation. The latter is subdivided into three parallel functional units: (1) nutritional bed, (2) shunt pathway and (3) storage area. By addition of simplified linear descriptions for the heart and pulmonary circulation, the overall cardiovascular system was considered. Parameter values were mainly derived from right heart bypass (Grodins, Stuart, and Veenstra, American Journal of Physiology, 1960 198, 552-560) and isolated hindlimb (Sato et al., 1971) experiments. An algebraic equation relating cardiac output to systemic circulatory parameters was derived which provided a convenient means of studying effects of parameter changes. This equation predicted that compliances and unstressed volumes have a unidirectional effect on cardiac output but arterial resistance has a variable effect which depends on the values of resistances and compliances of the parallel pathways. Circulatory responses to exercise were considered by changing compliance and resistance of the nutritional bed in accordance with experimental values obtained with a frequency response method (Vega, Ph.D. Thesis, University of Southern California, 1973). Possible mechanisms for blood flow restoration as required by the resistance change are discussed.

In summary, systemic circulatory mechanics appear to influence cardiac output mainly by redistribution of blood volume between different segments rather than by redistribution of blood flow.

INTRODUCTION

The importance of peripheral circulatory mechanics on cardiac output regulation has been established by many theoretical and experimental studies (Guyton et al., 1973). Until recently, however, models for the peripheral circulation used for quantitative analysis of overall circulatory behavior have been relatively simple. Thus, in one early model of the overall cardiovascular system (Grodins,
1959), the peripheral circulation was represented by a single 'peripheral resistance' placed between arterial and venous compliances. A similar analysis has been performed by Guyton (1955) who introduced the concept of mean circulatory filling pressure and resistance to venous return. These two variables correspond to a model comprising two resistances with a compliance between them. Following these initial studies, experimental data on circulatory mechanics have been accumulating which necessitates an expansion of peripheral circulation models. The importance of parallel pathways in the systemic circulation has recently been focussed on by several investigators (Permutt, 1973, and Stene et al., 1971). For the past several years, the present authors have been studying the mechanical properties of isolated perfused vascular beds with dynamic testing methods, and have obtained parameter values for the arterial, capillary, venous, and tissue compartments of several of these parallel circuits at rest and during exercise (Sato et al., 1971, 1972, 1973a,b, Yamashiro et al., 1972, and Vega, 1973).

The aim of the present study is to incorporate these models of the different vascular beds into a model of the entire systemic circulation, and to examine the implications of this model on cardiovascular regulation, specifically the behavior of cardiac output.

For maximum clarity and understanding, these relationships will be discussed in terms of simple linearized equations insofar as these simplifications do not distort the implications of the more rigorous analysis.

MODELS AND METHODS OF CALCULATION

1. Systemic Circulation

The model of the systemic circulation is composed of an arterial segment, a venous segment, and a peripheral circulatory bed (Fig. 1). The arterial segment (of compliance \( C_A \)) extends from aorta to medium sized arteries, and the venous segment (of compliance \( C_V \)) includes the vena cava, large veins, and medium sized veins. We assume no significant pressure gradient within the two respective segments. The variable resistance between right atrial pressure \( (P_{RA}) \) and vena cava pressure \( (P_V) \) represents the intermittent collapse of the veins in the

![Diagram](attachment:image.png)

**Fig. 1.** Model of systemic circulation. The black box containing the peripheral vascular beds is inserted between the large arteries \( (P_A,C_A) \) and large veins \( (P_V,C_V) \). The variable resistance \( (R_{VA}) \) between the right atrium and large veins is assumed to be negligible in this study.