VOLUME 8

Editors
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Lerner B. Hinshaw

ADVANCES IN SHOCK RESEARCH

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VOLUME 8

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Part 2

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Preface

Volume 8 of ADVANCES IN SHOCK RESEARCH consists of a collection of manuscripts derived from presentations made at the Fourth Annual Meeting of the Shock Society, held June 4–6, 1981, on Marco Island, Florida. It is intended as an extension of and complement to Volume 7, which is devoted entirely to papers on endotoxic and septic shock. In recent years, the extensive literature on these forms of shock has overshadowed other forms of shock; this book will serve to counteract this tendency and establish a balance.

The focus in this volume is on "Other Forms of Shock" and includes the classic forms with long histories of study: hemorrhagic, hypovolemic, cardiogenic, ischemic, traumatic, and anaphylactic. It is hoped that these papers will refresh the reader's memory in the area of pathophysiology and challenge his thinking in regard to new mechanistic insights and proposed methods of treatment.

The volume is composed of six distinctive sections, including papers dealing with mechanisms or treatment of shock, two symposia, a workshop, and a summary of all the material included in both Volumes 7 and 8. Among the topics covered in the papers are the functional significance of a variety of parameters, including intestinal mucosal lesions, thoracic duct lymph flow, proteolytic enzyme levels, sympathetic nervous system dysfunction, fibronectin, and reticuloendothelial function in experimental shock studies. Beneficial effects of ATP-$MgCl_2$, prostaglandin, epinephrine, and methyl prednisolone administration in experimental animals and in human subjects are described. The symposium on microcirculation deals with hemodynamic responses of vascular beds in shock, the passage of red cells and plasma in the microvasculature, and the undesirable effects of high hematocrits in low flow states.

A new emphasis on clinical problems, procedures, and treatments has been introduced into the Shock Society. We have therefore introduced a new type of symposium creating a balance between the work of clinicians and that of "basic scientists." Of particular note are the symposium on the pulmonary circulation and the workshop on monitoring patients with multiple organ failure. The former reviews the responses and mechanisms of hypoxic pulmonary vasoconstriction and the importance of neuroendocrine and metabolic factors in the regulation of pulmonary circulation. The latter reviews aspects of

immunologic, respiratory, and neurological monitoring of patients in shock. Practical clinical procedures and insights into the human problems encountered in shock should do much to unite the basic researcher and the clinician in more promising directions for collaborative research.

Despite the diversity of etiologies in the shock-like states, fundamental cellular mechanisms appear to be similarly altered. Continuing efforts to investigate events early in pathophysiological states will lead to better understanding of these conditions and provide the physician with a better basis for treatment.

It is an impossible task to summarize adequately the significance of so great a variety and complexity of areas as are represented in these two volumes; however, we hope that the reader will take away valuable impressions, insights, and ideas for future work.

Sherwood M. Reichard
Lerner B. Hinshaw

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Importance of Hypoxic Pulmonary Vasoconstriction With Atelectasis

Bryan E. Marshall

This survey summarizes information on various factors that determine responses to hypoxic pulmonary vasoconstriction. The emphasis is on the clinical relevance of these responses for atelectasis. Flow diversion reduces the functional effect of lung collapse by redistributing the pulmonary blood flow so as to promote restoration of arterial oxygen tension.

The factors shown to influence the outcome include size of the atelectactic segment, mixed venous oxygen tension, intrapleural and intraalveolar pressure (transpulmonary pressure), cardiac output, and pulmonary transmural vascular pressure.

INTRODUCTION

Atelectasis is associated with arterial hypoxemia and is a frequent occurrence in a wide variety of clinical situations. This essay will discuss the importance of hypoxic pulmonary vasoconstriction in determining the extent of hypoxemia when atelectasis occurs.

HYPOXIC PULMONARY VASOCONSTRICTION

When alveolar oxygen tension is reduced in some regions of the lung precapillary vasoconstriction is induced proximal to that region [2]. The result is that blood flow is diverted from the hypoxic region to the normoxic region and arterial oxygen tension does not decrease as much as it would have. This phenomenon is called hypoxic pulmonary vasoconstriction (HPV) and is an important fine control in the adjustment of ventilation-perfusion ratios in the lung. In addition to resulting in flow diversion (FD), HPV always induces an increased

pulmonary vascular resistance and therefore for the same total blood flow the perfusion pressure will be increased once HPV has occurred. The dual nature of the response to HPV is very important because the continuous nature and predictability of the response in different preparations becomes apparent [3] and also appears to account for many situations in which an acute increase in pulmonary vascular resistance occurs in association with respiratory impairment.

Previous publications have discussed the factors determining the magnitude of the flow diversion and perfusion pressure responses to alveolar hypoxia [3,4]. Interrelationships between the various factors are summarized in Figures 1 and 2. The perfusion pressure response is seen to be a direct curvilinear function of the size of the lung segment affected—the greater the size of the hypoxic lung

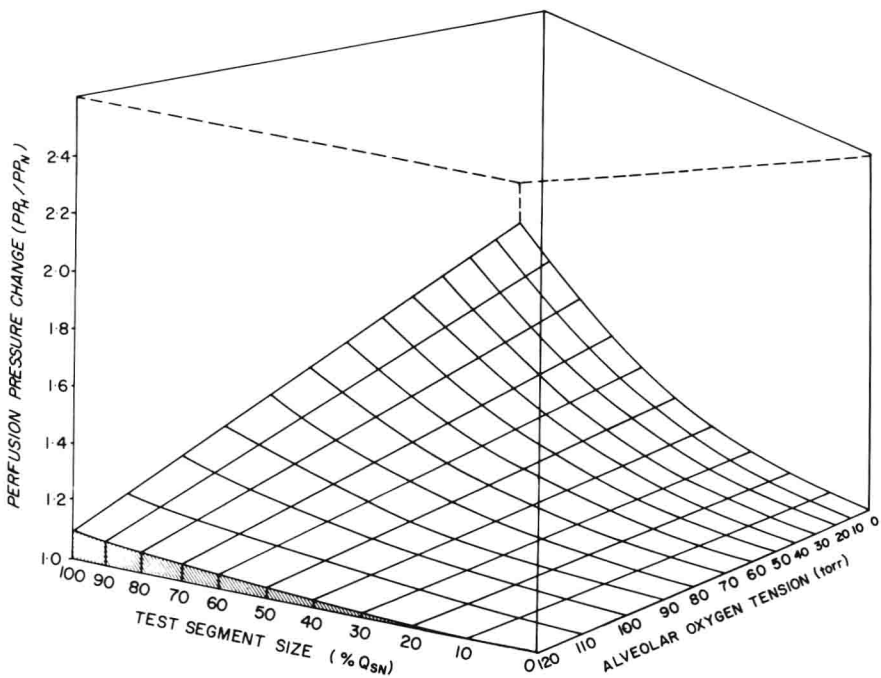

Fig. 1. Perfusion pressure response to hypoxic pulmonary vasoconstriction is shown to be a curvilinear function of test segment size and a linear function of alveolar oxygen tension in this three-dimensional represenation (of the data for reference [4]).

the greater the increase in perfusion pressure. In addition, for any specific hypoxic segment size (test segment) the response is represented as a linear inverse function of the alveolar oxygen tension.

For flow diversion the influence of test segment size is reversed. The relationship is curvilinear but now as the test segment size increases, flow diversion is reduced and becomes zero when the entire lung is hypoxic (test segment = 100%). For any specified test segment size the flow diversion response is again represented as a linear inverse function of alveolar oxygen tension. In addition, Figure 2 shows that mixed venous oxygen tension also influences FD. The clear (unshaded) response surface relates the FD to test segment size and to PAO_2 when mixed venous oxygen tension is greater than 40 torr. When mixed venous

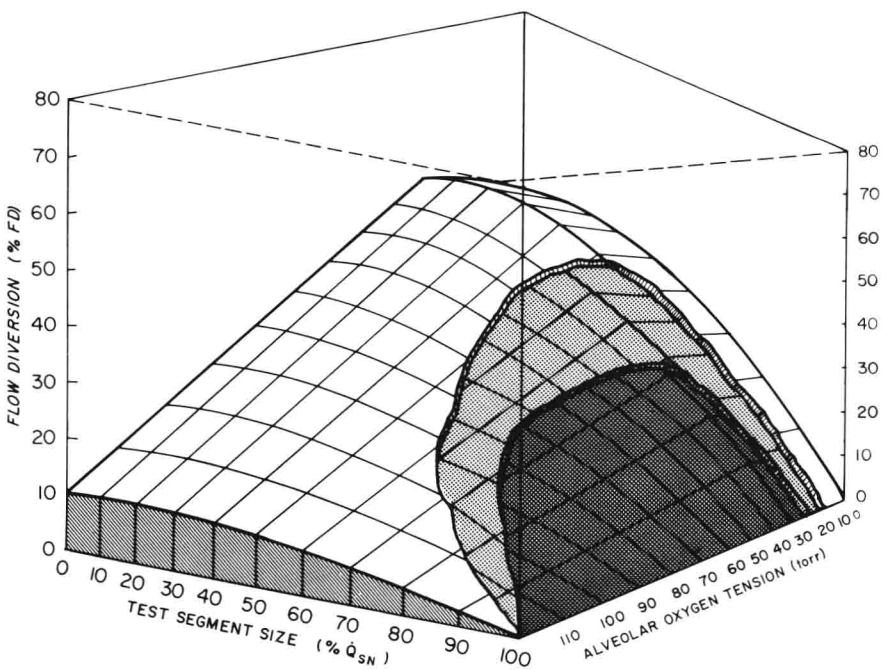

Fig. 2. Flow diversion during hypoxia is indicated on the vertical axis expressed as percentage of the flow during normoxia (ie, FD% = 60% means that during hypoxia the blood flow is reduced by 60% of the flow observed during normoxia). Flow diversion is shown to be a curvilinear function of test segment size and a linear function of alveolar oxygen tension until the maximum FD is reached at PAO_2 = 30 torr (from the data of reference [4]).

oxygen tension ($P\bar{V}O_2$) is less than this, flow diversion is reduced. The figure therefore shows portions of this surface cut away to reveal additional response surfaces underneath; the lightly stippled region corresponds to a $P\bar{V}O_2$ of 30 torr while the darkest region is the response surface when $P\bar{V}O_2$ is 20 torr. The reduction of flow diversion occurs because when $P\bar{V}O_2$ is less than 40 torr a progressive constriction is induced in normoxic regions of the lung and an increase in perfusion pressure necessarily results. Whenever perfusion pressure increases, flow diversion is reduced [3].

HPV WITH ATELECTASIS

For an open chest, in vivo, lung model the effects of atelectasis on FD and perfusion pressure have been reported to be similar to ventilating the same segments with a hypoxic gas mixture. With atelectasis the mixed venous oxygen tension has a special importance. Since there is no alveolar ventilation in the atelectatic area the oxygen tension of the region soon becomes close to that of the mixed venous blood; the mixed venous oxygen tension therefore replaces the alveolar oxygen tension in determining the initiation of hypoxic pulmonary vasoconstriction. The relationship described for HPV from experiments with ventilating lung lobes with hypoxic gas mixtures can be applied to atelectasis. The hypoxic test segment is now replaced by the portion of the lung that is atelectatic. It is apparent from Figures 2 and 3 that normal mixed venous oxygen tension of 40 torr is close to that alveolar oxygen tension that is associated with maximal vasoconstrictor response. At the same time the influence of mixed venous oxygen tension itself on the normoxic (nonatelectatic) lung, which was shown by the shaded response surfaces in Figure 2 to oppose flow diversion, is not a strong one at or above 40 torr.

By definition, in the absence of flow diversion from the atelectatic region, all mixed venous blood perfusing it will be mixed with oxygenated blood from the normoxic remainder of the lung and therefore an increase of pulmonary shunt percentage will occur proportional to the size of the atelectatic segment. The effects of different proportions of atelectasis are shown in Figure 3. The dashed line and filled circles predict arterial oxygen tension expected in the absence of HPV whereas the solid line indicates the arterial oxygen tension to be expected if hypoxic pulmonary vasoconstriction was maximally effective. The relationship demonstrates that a very effective protection against arterial hypoxemia is provided for atelectatic regions ranging from about 20% to 50%. For example, when 30% of the lung is atelectatic while the rest of the lung is ventilated with oxygen, the resulting arterial oxygen tension may be 400 torr greater as a result of HPV.