important area in which anesthesia differs from other specialties. Failure to recognize these differences in response, and to recognize them in time to recover from either error or varying response, is rarely the drug's fault.

There is little doubt that drugs with such powerful effects on vital functions as anesthetic agents possess will result in harmful effects on occasion even in the best of hands. It must be admitted that idiosyncratic reaction can occur, and with the myriad drugs now used, serious drug interactions must remain a possibility. The important controversy, then, is the relative role of drugs as causative elements in anesthetic mortality, as opposed to the role of management error. Cliches may be used to suppport either view. On one hand it is said "we don't debate safe versus dangerous anesthetic agents—only which is the least dangerous"; on the other "There are not bad anesthetics, only bad anesthetists." While it is mathematically imprudent to conclude that mortality or near-catastrophe occurs *only* as a result of misuse or error, we must consider probabilities, especially when they are overwhelming. Practically, it boils down to the statement in Dr. Keats' text ". . . it is important to know whether anesthetic deaths attributable to error amount to 10 or 90 per cent." In my view, error is near the 90 per cent end.

Dr. Keats' article will probably be most popular. It offers salve to our conscience and provides at least a glimmer of hope and defense in malpractice situations. Life is easier when our problems, especially the serious ones, can be blamed on the tools of our trade, our patients, the gods,—or anything else that has an aura of unavoidability. What is Dr. Keats' final message? To the extent that he says "don't make decisions without proper basis," I agree wholeheartedly. To the extent that his theme is that drugs *per se* are numerically an important cause of anesthetic mortality, I disagree strongly. This opinion is based on the statistical probabilities, or improbabilities of drug behavior. It is further based on experience that has repeatedly seen error produce predictable response. This view in *no way* states that drugs can *never* be causative, or even suggests that all error is avoidable, or that benefits are not achieved without certain definite risk. There is room for all these to coexist.

WILLIAM K. HAMILTON, M.D.
Professor and Chairman
Department of Anesthesia
University of California
School of Medicine
San Francisco, California 94143.

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Dr. Starling and the "Ventilator" Kidney

ONCE, a time few can remember, the pattern of breathing was described in simple terms: fast or slow, shallow or deep, quiet or labored. Later, the stethoscope and the trained ear added a new dimension to our interpretation of the sounds of breathing. Unfortunately, during progress from less art to more science, we have improved the instruments but forgotten the music. In fact, our penchant for innovation has promoted the use of a language without grammar and a branch of science best characterized as the physiology of iatrogenesis. "To breathe" is no longer enough; it is now ventilation, controlled, mechanical or not, intermittent, mandatory or not, with or without PEEP, CPAP, and many more. The juggernaut of abbreviations threatens to gain momentum; so does the complexity of iatrogenic abnormalities and their grotesque description in terms such as "respirator" lung, "respirator" brain, and many more. One shudders to contemplate the possibility that acute pancreatitis, developed during mechanical ventilation, may someday be described as "respirator" pancreas!

Now we have moved in a new direction which, for lack of more elegant terminology, I propose to call the natural history of the "ventilator" kidney. In this issue, Marquez *et al.*[1] provide nourishment for thought and an opportunity to consider the qualitative differences in the responses of the lung, normal or otherwise, the heart, normal or otherwise, and, as we have long suspected, the kidney, normal or otherwise, to breathing with added airway pressure. Their study raises two questions: one minor, the other major,

Key words: Kidney: blood flow; function. Ventilation: mechanical.

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TABLE 1. Proposed Abbreviated Nomenclature for Ventilatory Patterns

Mode of Ventilation	Airway Inspiration/Expiration Pressure Pattern	Proposed Abbreviation
Continuous mandatory (mechanical) ventilation	Intermittent positive–negative	CMV with NEEP
	Intermittent positive	CMV with ZEEP
	Continuous positive	CMV with PEEP
Intermittent mandatory ventilation	Intermittent positive–negative	IMV with NEEP
	Intermittent positive	IMV with ZEEP
	Continuous positive	IMV with PEEP
Spontaneous ventilation	Ambient	SV with ZEEP
	Continuous positive	SV with PEEP

deserving of comment. The first, or minor, point is to challenge the desirability of using abbreviations that characterize patterns of ventilation with a looseness we accept for the daily press, but not for scientific journals. Although abbreviations are common and tolerated, they do violate the principles of good writing style and, more important, are quickly abused by individuals who have a propensity for innovation. Fortunately, a beginning effort in the right direction has been published.[2] It deserves appropriate attention, although its complexity may militate against routine use in scientific communications. Since few have tried, it seemed appropriate to present an alternative. Why do it? Simply because attention to linguistics obviates confusion. Marquez *et al.*[1] used two patterns of breathing, which they labelled continuous positive airway pressure ventilation (CPPV) or continuous positive airway pressure (CPAP). Strictly speaking, this terminology is not justified, because ventilation, *i.e.*, spontaneous or controlled, and continuous positive airway pressure are present in both. In the recommended terminology, CPPV is best described as controlled mandatory ventilation with positive end-expiratory pressure (CMV with PEEP), to contrast with intermittent mandatory ventilation (IMV), and CPAP is to be described as spontaneous ventilation with positive end-expiratory pressure (SV with PEEP), as shown in table 1.

TABLE 2. Hemodynamic and Renal Functions during Ventilation with Different Airway Pressure Patterns

		CMV with PEEP	SV with PEEP
Transmural mean aortic pressure (torr)	Inspiratory	113.0 ± 1.3	130.3 ± 1.7
Transmural left ventricular end-diastolic pressure (torr)	Inspiratory	4.9 ± 1.5	8.9 ± 1.9
	Expiratory	4.6 ± 1.3	5.6 ± 1.0
Renal vein pressure†	—	Increased*	Increased*
Cardiac output	—	Decreased*	No change
Plasma vasopressin concentration	—	Increased*	No change
Urinary flow	—	Decreased*	Decreased*
Urinary Na^+	—	Decreased*	No change
Glomerular filtration rate	—	Decreased*	Decreased*

* Compared with control values.

† Calculated from values given for $P_{\overline{IVC}}$ in table 1 by Marquez *et al.*[1]

Such recommendations are intended as a plea for uniformity to replace terminology utilized according to personal prejudices. Since the value of these therapeutic modalities is well established, further accolades are unnecessary. Criteria of excellence in publication require a terminology easily understood and free of confusion, particularly if such reports are to be read and understood 25 years hence.

The second point is by far more interesting, and addresses itself to the effects of increased airway pressure on renal function. Marquez *et al.*[1] have compared hemodynamic and renal responses to two patterns of ventilation; one supported by mechanical means, the other spontaneous. Their results are summarized in table 2. Fortunately, the data include values for inferior vena caval (IVC) or renal vein pressures, and transmural left ventricular filling pressures, the latter as recorded during inspiration and expiration, thereby providing a clue to the multiplicity of factors that affect renal performance. According to table 2, the values for blood flows into the right heart and the left heart were similar during expiration but markedly different during inspiration. Since cardiac output was unchanged during SV with PEEP but decreased during CMV with PEEP, we can assume that inflow was enhanced substantially during the inspiratory phase of spontaneous breathing. Although one may be tempted to attribute the lower cardiac output during controlled ventilation to a decrease in venous inflow, such a conclusion appears premature. Table 1 in the paper by Marquez *et al.*[1] reveals that stroke volumes decreased significantly with both patterns of ventilation, but

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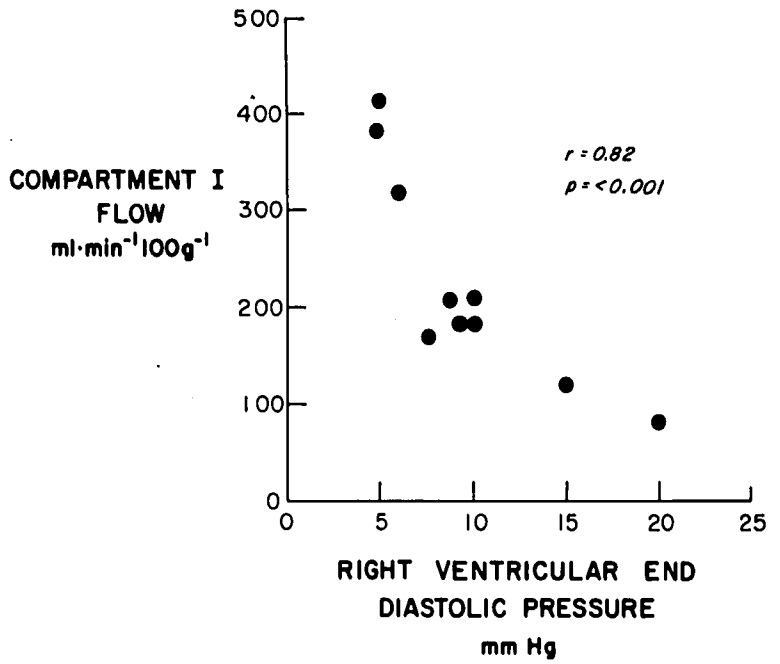

FIG. 1. Relationship between right ventricular end-diastolic pressure and blood flow to the outer cortex of the kidney (Compartment I flow), determined by the ^{133}X washout technique. The data were collected from seven patients with various degrees of right ventricular failure. There was no apparent relationship between cardiac output and Compartment I blood flow. (Reproduced with permission from Kilcoyne MM, Schmidt DH, Cannon J: Intrarenal blood flow in congestive heart failure. Circulation 47:786–797, 1973.)

more so during CMV with PEEP. Part of the answer probably lies with the variations in phasic venous inflow or the preload, the other with *transmural* aortic pressure, a component of left ventricular afterload, which was substantially higher during inspiration only in the SV-with-PEEP group. Thus, the decrease in stroke volume may have been related to preload in one group (CMV with PEEP) and related to afterload in the other (SV with PEEP).

Like the heart, the kidney appears to respond to variations in "preload" (*i.e.*, arterial blood pressure and flow), as well as "afterload" (*i.e.*, venous blood pressure and flow), in addition to a variety of humoral stimuli. The profound influence of a decrease in cardiac output or systemic arterial pressure is universally appreciated and requires no comment. However, little attention has been devoted to the possible effects of an acute and sustained increase in renal vein pressure on renal function in the patient whose heart and kidneys were previously healthy. Studies in the experimental animal suggest that acute, thoracic inferior vena caval constriction does affect renal function. For example, Friedler *et al.*[3] reported that acute occlusion, which causes pressures in the inferior vena cava to exceed 10 torr, was associated with decreases in glomerular filtration rate (GFR) and sodium retention, as well as a decrease in the natriuresis following a subsequent infusion of saline solution. Vasodilation with acetylcholine and administration of angiotensin to restore arterial blood pressure or increase it to above control values resulted in increased sodium excretion following the infusion challenge, without an additional increase in GFR.

Schrier and Humphreys[4] compared the effects of acute constriction of the thoracic and abdominal inferior vena cava on renal function under conditions where *renal perfusion pressure* (RPP, or mean aortic minus mean renal venous pressure) was controlled. In this setting, increased renal venous pressure resulted in diminished urinary sodium excretion, which was reversed by increasing RPP to control values. Analysis of their data suggests that if cardiac output were to remain unchanged, a progressive increase in renal venous pressure would result in greater sodium retention. If this information were applied to the clinical environment, then we might conclude that each increment in IVC pressure must be associated with a corresponding increase in mean aortic pressure to maintain RPP constant and, if cardiac output is maintained, normal salt and water balance will ensue. Unknown is the answer to the question whether normal sodium handling, including the response to a sodium load, is possible only when RPP and CO are both *increased* to above control levels as renal venous pressure is increased. Whatever the result, the role of renal venous pressure as a component of perfusion pressure cannot be ignored.

The postulated relationship between venous pressure and altered distribution of renal blood flow has been demonstrated in the human patient with congestive heart failure and edema by Kilcoyne *et al.*[5] According to these investigators blood flow to the outer cortex of the kidney was decreased commensurate with an increase in right ventricular end-diastolic pressure (fig. 1). Unfortunately, the role of a diminished cardiac output, as compared with that in normal individuals,

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could not be assessed. Nevertheless, the data of table 2 suggest that three variables influence renal function consequent to increased airway pressure, in addition to other poorly-identified humoral factors. First, the modest decrease in blood flow due to a diminished thoracic venous return limits renal cortical perfusion. In the presence of acute respiratory failure with pulmonary vascular changes, the increased right ventricular afterload may contribute to this effect. Second, plasma vasopressin concentrations are increased, but not when spontaneous ventilation is maintained. Although the mechanism is not defined, we may assume that baroreceptors play a role.[6] Lack of a difference in left atrial transmural pressures during expiration and an increase rather than decrease during inspiration with spontaneous ventilation with PEEP implies sites other than the left atrium. In a recent review of nonosmolar factors that affect renal water excretion, Schrier and Berl[6] presented evidence that suggests that carotid baroreceptors play a role. The finding of a decrease in transmural aortic pressure during mechanical but not spontaneous ventilation supports this hypothesis. Third, as demonstrated so beautifully by Earley and colleagues,[7] renal peritubular capillary hydrostatic pressure will reflect an increase in inferior vena caval pressure and enhance sodium reabsorption. In essence, this represents a decrease in renal cortical blood flow initiated by increased renal venous pressure without an alteration in forward flow and pressure. It is supported by experimental data describing intrarenal distribution of blood flow during positive-pressure ventilation.[8]

In the final analysis, the variables controlling renal function are not unlike the principles applied by Dr. Starling to define function of the heart and the principles of water balance in the lung. It would appear that the kidney does take its cues from the lungs, subjected to higher than usual airway pressures, and the responses may be sufficiently intense to be of clinical concern. Assuming a decrease in renal cortical blood flow or cortical ischemia is indeed a result of the increased right atrial pressure generated by ventilator assistance, the appearance of renal dysfunction during therapy for acute respiratory failure, despite the absence of obvious initiating factors (*i.e.*, prolonged hypotension, hemorrhage, nephrotoxins, etc.), may be explained. In any event, these postulates clarify the sequence that culminates in significant water retention. Considered in teleologic terms, intravascular volume expansion, intended to overcome the deleterious hemodynamic consequences of mechanical ventilation, is precisely what the kidney sets out to do, because it responds to signals from the arterial and venous side. One may wonder whether evolution, in its wonderful ways, foresaw the eventual need for adaptive responses during mechanical support of breathing. The answer is, probably not, and conjecture over this possibility is less likely to bear fruit than further study of the model. Thus, the association between ventilator and renal function will have been established, with the ground rules recognized more than half a century ago by Dr. Starling.

MYRON B. LAVER, M.D.
Professor of Anesthesia
Harvard Medical School at
Massachusetts General Hospital
Boston, Massachusetts 02114

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