

Pulmonary Hemodynamics during Induction of Anesthesia

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Changes in pulmonary hemodynamics and acid-base balance were recorded during induction of anesthesia using either intravenous administration of a barbiturate (28 patients) or inhalation of N₂O-O₂-halothane (12 patients). The two types of induction resulted in equal elevations of pressures within the pulmonary circulation. The increase, proportional on the two sides of the heart, was most pronounced immediately before endotracheal intubation. Cardiac index decreased before and during intubation but subsequently increased to levels above control values. Systemic blood pressure increased more during barbiturate than during inhalation induction. Changes in acid-base balance were similar during the two types of induction: arterial blood P_{CO₂} and P_{O₂} increased, pH decreased, and standard bicarbonate remained unchanged. Changes in pulmonary arterial mean pressure and central venous pressure were correlated with changes in Pa_{CO₂}. Pulmonary capillary filtration pressure (i.e., pulmonary capillary wedge pressure minus plasma colloid osmotic pressure) was negative in every patient before anesthesia. During induction of anesthesia, filtration pressures became positive in half the patients. Observed changes in circulation may have been caused by hypercapnia alone or by a combination of hypercapnia and vascular reflexes associated with instrumentation during intubation. The increased strain on the heart during induction of anesthesia may lead to cardiac failure in patients with diminished cardiac reserve. (Key words; Lung, pulmonary hemodynamics; Induction, anesthesia.)

DURING STEADY-STATE ANESTHESIA, pulmonary arterial pressure increases markedly during ether and cyclopropane anesthesia,¹ and moderately during barbiturate (Narkotal = enibomalnatrium NFN)-*d*-tubocurarine anesthesia.² The effects of induction of anesthesia on pulmonary hemodynamics have not been as fully quantitated. Prys-Roberts *et al.*³ observed an elevation of pulmonary arterial pressure following thiopental induction and endotracheal intubation. Thiamylal has also been found to increase pulmonary arterial pressure for the first 8 minutes after injection in trained dogs, but pentobarbital has little effect.⁴

The purpose of the present study was to evaluate acute changes in pulmonary hemodynamics in man immediately after induction of anesthesia and to relate these changes to the type and course of anesthesia.

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Material and Method

Swan-Ganz flow-directed catheters⁵ were inserted in 40 patients without cardiac or respiratory insufficiency to monitor the pulmonary circulation during induction of anesthesia prior to elective peripheral vascular surgery. The catheter was introduced through the cubital or the external jugular vein, either by use of the percutaneous Seldinger technique⁶ or by surgical exposure of the vein. Two Statham P 23 db transducers applied at the mid-axillary line of the patient placed supine on the operating table were used for measurement of pulmonary arterial mean pressure (PAMP), pulmonary capillary wedge pressure (PCWP), and central venous pressure (CVP). Cardiac output (CO) was measured by dye dilution (CO_{dy}) with the apparatus constructed by Zijlstra and Mook,⁷ or by thermal dilution (CO_{th}) using a Swan-Ganz thermodilution catheter⁸ and a battery-driven cardiac output computer (Cardiac Output Computer model 9500, Edwards). A previous study has shown satisfactory agreement between the two methods for cardiac output determination.⁹ Systemic blood pressure was measured on a P 23 db transducer through a catheter within the radial artery. This catheter was also used for sampling blood for gas analysis and acid-base determination. These measurements were made using a Radiometer electrode assembly. It was not always possible to make all measurements in all patients.

The height-and-weight nomogram of Dubois¹⁰ was used for calculation of cardiac index (CI). Pulmonary vascular resistance was calculated from the formula:

$$\frac{(\text{PAMP} - \text{PCWP}) \cdot 80}{\text{CO}} \cdot \text{dynes} \cdot \text{sec} \cdot \text{cm}^{-5}$$

The patients were premedicated one hour prior to anesthesia with meperidine/atropine or diazepam/scopolamine, according to weight. In Group I, comprising 28 patients (23 male, five female) aged 19 to 71 years (mean 53 years), anesthesia was induced with intravenous administration of atropine, barbiturate (enibomalnatrium NFN), and succinylcholine. In Group II, the 12 patients (six male, six female), aged 38 to 75 years (mean 56 years) were anesthetized without previous atropinization by inhalation of N₂O (50 per cent)-O₂ and halothane. Endotracheal intubation was accomplished in all patients, but without relaxants in eight patients in Group II. In Group I anesthesia was induced according to the general principles of this depart-

ment by various anesthetists, who had not been informed of the purpose of the study. Patients in Group II were anesthetized by the same anesthetist. Hemodynamic and respiratory measurements were made before anesthesia, one minute prior to intubation ("after induction"), and at the time of intubation. After intubation, measurements were performed every second minute during the first 10 minutes and then once during the next 10 minutes (see figs. 1-4). Excluded were data obtained during periods of muscular straining or coughing. To determine the significances of observed changes, paired differences between the observations made for the different time groups were examined with Student's *t* test for paired data, assuming a normal distribution of the observations. To determine whether the

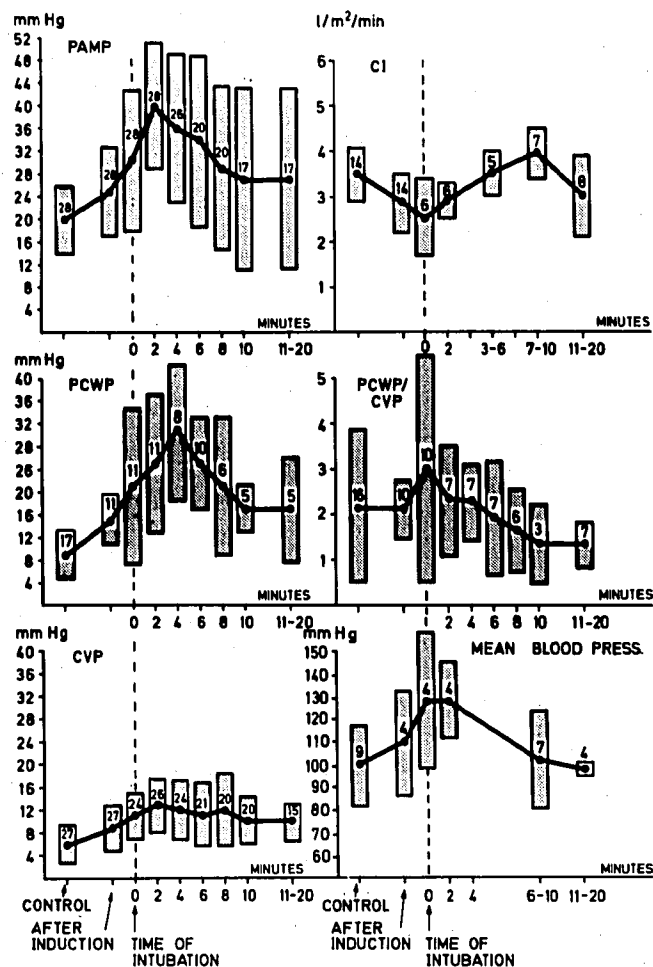


FIG. 1. Mean values illustrating the courses of hemodynamic variations in 28 patients during induction of anesthesia with barbiturate (enibomalnatrium NFN) and succinylcholine. Rectangles denote standard deviations and figures within, the numbers of observations. PAMP = pulmonary artery mean pressure; PCWP = pulmonary capillary wedge pressure; CVP = central venous pressure; CI = cardiac index; mean blood press = systemic mean blood pressure.

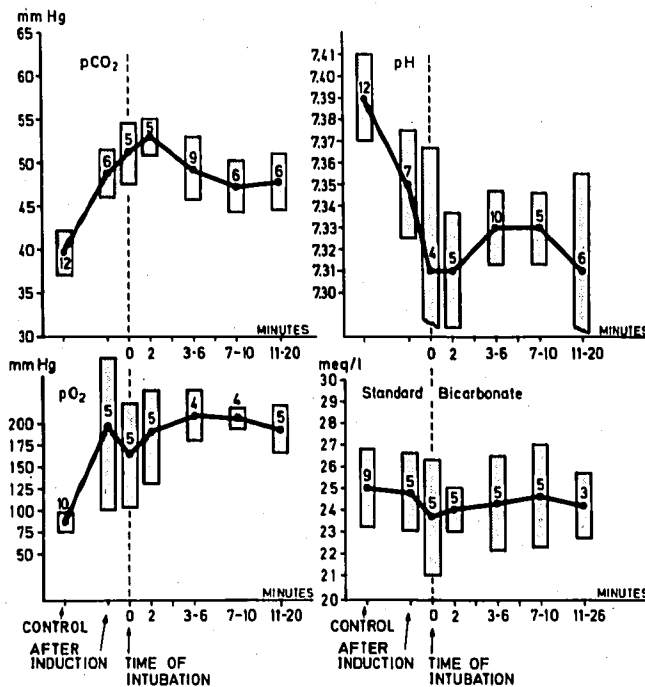


FIG. 2. Mean arterial blood acid-base values in 28 patients during induction of anesthesia with barbiturate (enibomalnatrium NFN) and succinylcholine. Rectangles denote standard deviations and figures within, the numbers of observations.

courses of the two types of anesthesia varied, we examined differences between the chronological time groups by means of Student's *t* test for unpaired data. In addition, changes in P_{aCO_2} were correlated with changes in the hemodynamic modalities.

Measurements of the plasma colloid osmotic pressure (COP) using a Tybjærg Hansen osmometer¹¹ were made in 25 patients, either on the day before or immediately prior to anesthesia, and from the difference between PCWP and COP the filtration pressure in the pulmonary capillaries was calculated.

Results

Changes in hemodynamics observed in Group I are shown in figure 1. The maximal average increase in pulmonary vascular pressure occurred some minutes after intubation, while maximal changes in systemic blood pressure coincided with intubation. Increases in PAMP and CVP were statistically significant both "after induction" and at the time of intubation, whereas PCWP changed significantly only after induction (table 1). The vascular resistance increased, but not significantly (table 2). The first 10 minutes after intubation thus produced significant decreases in PAMP and CVP ($P < 0.05$). Acid-base changes (fig. 2 and table 1) included significant elevation of P_{CO_2} and decrease in pH, but standard bicarbonate remained unchanged. After intubation and following ventilation, P_{CO_2} decreased,

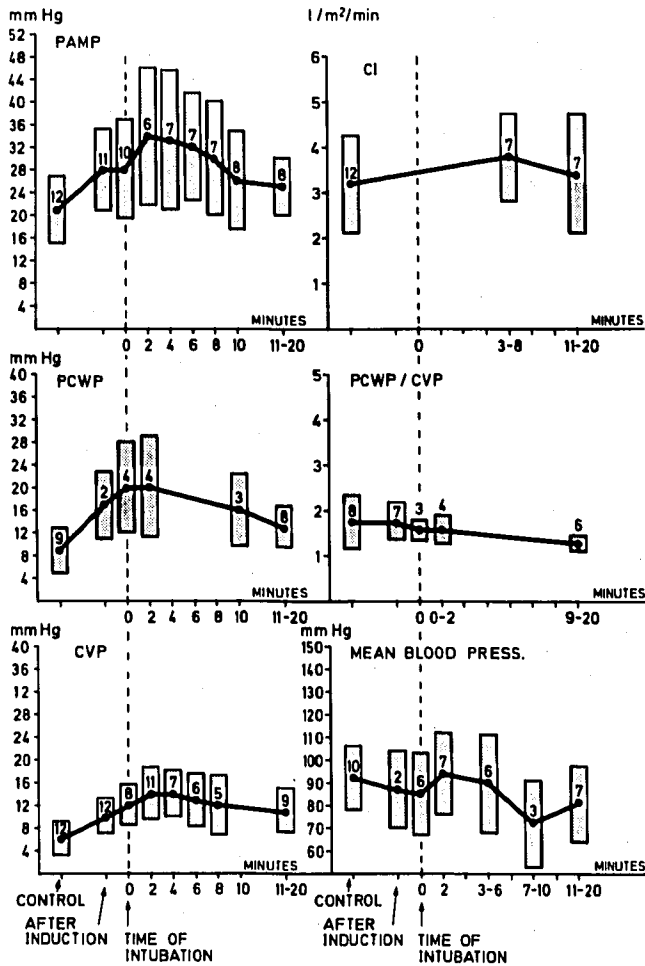


FIG. 3. Mean values illustrating the courses of hemodynamic variations in 12 patients during induction of anesthesia with inhalation of N₂O-O₂-halothane. Rectangles denote standard deviations and figures within, the numbers of observations. PAMP = pulmonary artery mean pressure; PCWP = pulmonary capillary wedge pressure; CVP = central venous pressure; CI = cardiac index; mean blood press = systemic mean blood pressure.

but it did not return to initial values during the period of study.

The hemodynamic data obtained in Group II are shown in figure 3, and the acid-base measurements in figure 4, with the statistical significances of observed changes summarized in table 3.

Table 4 relates changes in pulmonary and systemic blood pressures to changes in P_{CO₂}. PAMP and CVP were significantly related to P_{CO₂}; MAP and PCWP were not. The regression line between ΔPAMP and ΔP_{CO₂} appears in figure 5.

In 25 patients, COP's ranged from 18.5 to 27.4 mm Hg (mean = 22.7 mm Hg, SD = 2.32). As shown in figure 6, all patients had negative filtration pressures before anesthesia, and none had signs or preoperative radiologic evidence of pulmonary edema.

During induction of anesthesia, filtration pressures rose in all patients but one (Patient 30), and positive filtration pressures were observed in 13 patients, none of whom, however, developed evidence of pulmonary edema.

Apart from the fact that systemic blood pressure increased significantly more in Group I (*P* < 0.05) than in Group II, hemodynamic responses to the two types of induction were similar.

Discussion

The systemic blood pressure increases during induction of barbiturate-nitrous oxide-oxygen-succinylcholine anesthesia,^{12,13} as well as during brief periods of inhalational anesthesia.¹⁴ In either case, sympathetic stimulation aroused by laryngoscopy and endotracheal intubation has been held responsible for an acute rise in pressure, which starts as the succinylcholine takes effect and accelerates during instrumentation of the larynx and trachea, with maximal elevation occurring 1-2 minutes after intubation.

Group I (fig. 1) closely followed this pattern, as also reported by Forbes and Dally,¹² whereas Group II (fig. 3) did not, perhaps because of deeper levels of anesthesia at the time of intubation with less reflex activity evoked by instrumentation. In spite of different effects on the systemic blood pressure, the two types of induction produced

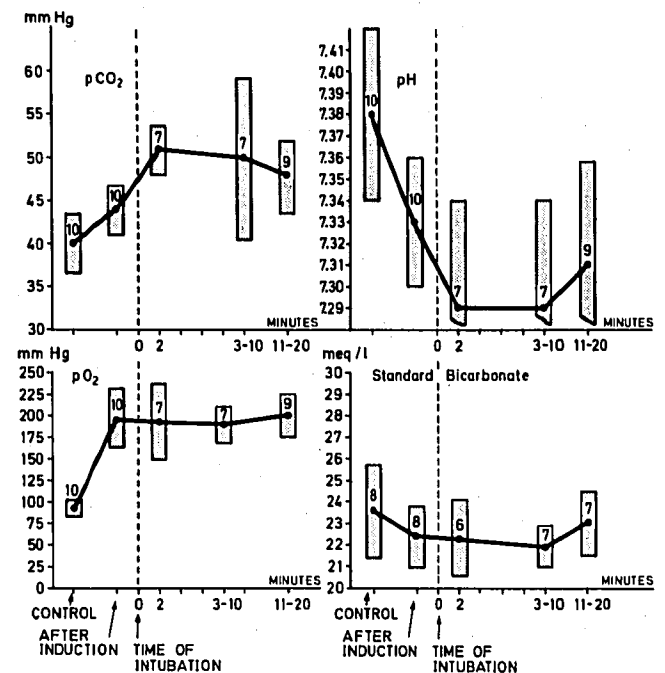


FIG. 4. Mean arterial blood acid-base values in 12 patients during induction of anesthesia with inhalation of N₂O-O₂-halothane. Rectangles denote standard deviations and figures within, the numbers of observations.

TABLE 1. Statistical Analysis of Significance of Changes in Hemodynamic and Acid-Base Values during Induction with Barbiturate

	Pulmonary Arterial Mean Pressure (PAMP)	Pulmonary Capillary Wedge Pressure (PCWP)	Central Venous Pressure (CVP)	PCWP/CVP	Blood Pressure	Cardiac Index	P _{CO₂}	pH	Standard Bicarbonate	P _{O₂}
Control-after induction	P < 0.001 n = 28	P < 0.05 n = 11	P < 0.05 n = 27	NS n = 10	NS n = 4	NS n = 9	P < 0.05 n = 6	P < 0.01 n = 7	NS n = 5	P < 0.05 n = 8
After induction-time of intubation	P < 0.001 n = 28	NS n = 8	P < 0.05 n = 24	NS n = 7	P < 0.05 n = 3	P < 0.05 n = 6	NS* n = 5	P < 0.01* n = 5	NS* n = 5	NS* n = 3
Control-time of intubation	P < 0.001 n = 28	P < 0.05 n = 11	P < 0.001 n = 24	NS n = 10	NS n = 4	P < 0.05 n = 6	P < 0.05* n = 5	P < 0.01* n = 5	NS* n = 5	NS* n = 4

n = number of paired observations. NS = not significant.
* 0-2 minutes after intubation instead of "time of intubation."

TABLE 2. Pulmonary Vascular Resistance (dynes · sec · cm⁻⁵) during Induction of Anesthesia with Barbiturate*

	Control	After Induction	At Intubation	After Intubation			
				2 Min	3-6 Min	7-10 Min	11-20 Min
Mean	119	101	176	127	110	119	118
Standard deviation	33.8	31.2	99.5	50.0	52.5	14.7	49.0
Number of observations	12	7	6	3	6	6	4

* Paired t test did not reveal any significant change in pulmonary vascular resistance.

TABLE 3. Statistical Analysis of Significance of Changes in Hemodynamic and Acid-Base Values during Induction by Inhalation

	Pulmonary Arterial Mean Pressure (PAMP)	Pulmonary Capillary Wedge Pressure (PCWP)	Central Venous Pressure (CVP)	PCWP/CVP	Blood Pressure	Cardiac Index	P _{CO₂}	pH	Standard Bicarbonate	P _{O₂}
Control-after induction	P < 0.05 n = 11	P < 0.05 n = 8	P < 0.01 n = 12	NS n = 7	NS n = 7	NS n = 3	P < 0.01 n = 10	P < 0.01 n = 9	NS n = 8	P < 0.001 n = 10
After induction-time of intubation	NS n = 9	NS n = 4	NS n = 8	NS n = 3	NS n = 5	—	P < 0.01* n = 7	P < 0.01* n = 7	NS* n = 6	NS* n = 7
Control-time of intubation	P < 0.05 n = 9	P < 0.05 n = 4	P < 0.01 n = 8	NS n = 3	NS n = 5	—	P < 0.01* n = 7	P < 0.01* n = 7	NS* n = 6	P < 0.001* n = 7

n = number of paired observations. NS = not significant.
* 0-2 minutes after intubation instead of "time of intubation."

equal elevations of pressures within the pulmonary circulation. Both groups also showed similar elevations of P_{CO₂} during induction, averaging 10 mm Hg, and a significant correlation was found between changes in P_{CO₂} and changes in PAMP and CVP.

The transition from spontaneous breathing to controlled ventilation increases intrathoracic and thus, intrapulmonary vascular pressures. In this series airway or intrathoracic pressures were not measured, but their influence on the observed increases in pulmonary pressures must have been small, as there was no significant difference between the two groups: inhalation induction with spontaneous

breathing and intravenous induction with controlled ventilation.

As CVP represents right atrial pressure, PCWP can for all practical purposes be considered identical

TABLE 4. Correlation between Changes in P_{CO₂} and Changes in Pulmonary and Systemic Pressure

	PAMP	CVP	PCWP	MAP
r	0.6456	0.3985	0.4626	0.069
Significance	P < 0.001	P < 0.05	P > 0.1	P > 0.1
Number of observations	32	35	12	23

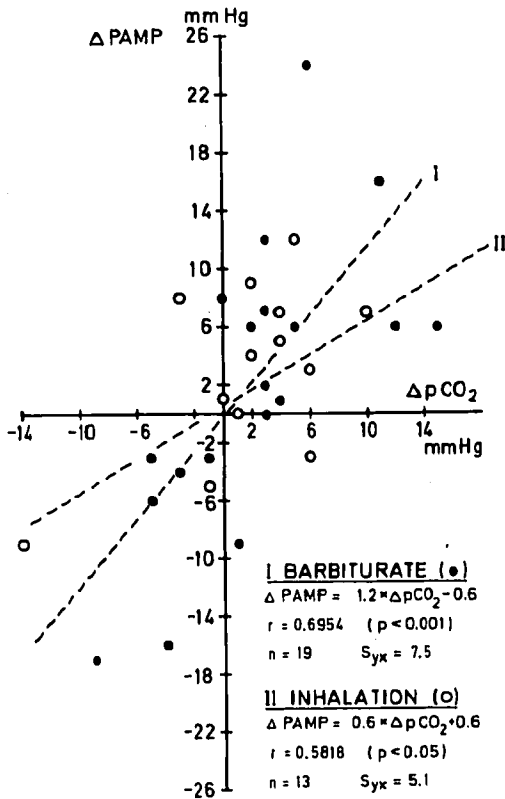


FIG. 5. Correlation between $\Delta PAMP$ and ΔP_{CO_2} during induction of anesthesia with barbiturate (enibomalnatrium NFN) and succinylcholine (closed circles) and with N_2O-O_2 -halothane (open circles).

to left atrial pressure.¹⁵ Presuming a constant Starling curve, atrial pressure is correlated with stroke work of the ventricle, except in valvular diseases.¹⁶ In normal conditions the ratio between the stroke work of the two ventricles will be constant; the ratio PCWP/CVP will therefore also be constant. When, however, disparity between the functions of the two ventricles occurs, the ratio will change. This is typically seen in left ventricular failure, when PCWP rises at a time when CVP remains unchanged or is only slightly increased.^{17,18} The ratio, however, is not very meaningful when CVP is less than 1 mm Hg. Thus, earlier investigators¹⁹ reported disproportionality between PCWP and CVP during induction of anesthesia in four patients. However, in our series no significant change in PCWP/CVP could be demonstrated, thus indicating a general effect on the both sides of the heart during induction of anesthesia and intubation.

The changes in pulmonary hemodynamics observed in the present study emphasize the value of monitoring pressures on both sides of the heart, since disproportional increases in atrial pressures indicate imminent cardiac failure. Pulmonary pressures during induction of anesthesia rose in some patients in the present series to a level corresponding to those observed during an exercise tolerance

test to the point of exhaustion.¹⁸ Other investigators²⁰ have found that extubation, too, can produce significant increases in pulmonary vascular pressures.

In calculation of filtration pressures during induction of anesthesia, preoperative COP values have been used, since COP remains relatively constant in individual patients, as shown by Ladegaard-Pedersen,²¹ who found COP to vary ± 15 per cent during a postoperative course.

The negative filtration pressure before anesthesia is in accordance with the absence of clinical or radiologic signs of pulmonary edema in these patients. Positive filtration pressures were observed in 13 of the 25 patients after anesthesia was induced. These pressures hardly represent true maximal values, however, since PCWP can be measured only intermittently due to the risk of pulmonary infarction if the occluding balloon is left inflated. Incipient pulmonary edema was not observed in any case, probably because of the short duration of the positive filtration pressure and because the positive filtration pressure was counteracted by IPPV.

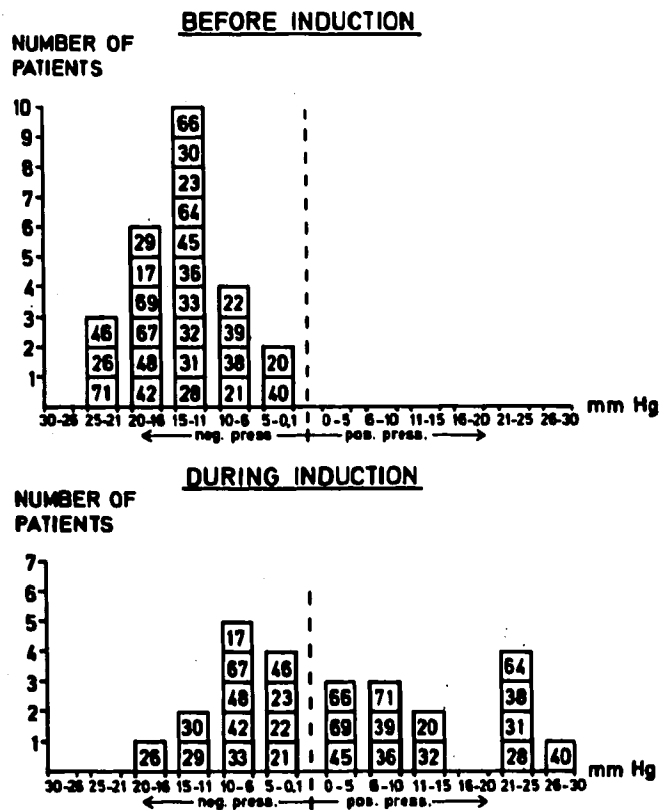


FIG. 6. Pulmonary capillary filtration pressure calculated as the difference between pulmonary capillary wedge pressure (PCWP) and plasma colloid osmotic pressure (COP). Before induction of anesthesia negative filtration pressures were observed in the pulmonary capillaries of 25 patients. During induction and intubation the filtration pressures rose in all patients except one (Patient 30), with the result that 13 patients had positive filtration pressures. Numbers in squares represent individual patients' protocol numbers, to demonstrate variation in individual patients.

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