

Postoperative Hypoxemia:

The Contribution of Age to the Maldistribution of Ventilation

Hirobumi Kitamura, M.D.,* Takeshi Sawa, B.S.,†
Etsutaro Ikezono, M.D.‡

Arterial blood gases were analyzed in 69 patients during breathing of room air and oxygen on the day before anesthesia and about two hours after anesthesia. Changes in uniformity of distribution of the inspired gas were also measured before and after anesthesia in 20 patients, using an open-circuit nitrogen-washout method. Significant negative correlations between P_{aO_2} and age were found during breathing of room air and 100 per cent oxygen both pre- and postoperatively. During breathing of room air, the slope of the regression line became significantly steeper after anesthesia; with oxygen, there was no significant change after anesthesia. The nitrogen clearance delay was significantly greater after anesthesia, and this increase was most significant in the elderly. There was a significant negative correlation between age and the difference between pre- and postoperative FRC's (per cent). These results indicate that postoperative hypoxemia can be attributed not only to intrapulmonary shunting but also to the mismatching of ventilation to perfusion owing to increasing abnormality of distribution of ventilation with advancing age. (Key words: Postoperative hypoxemia; Arterial oxygen tension; True shunt; Ventilation-perfusion ratio; Maldistribution of ventilation; Nitrogen clearance delay.)

IN A REVIEW of the causes of early postoperative hypoxemia,¹ two major factors were identified: the decrease in efficiency of oxygenation in the lungs owing to increased venous admixture from true shunt² and/or mismatching of ventilation to perfusion,³ and a decrease in mixed venous saturation secondary to a decrease in cardiac output, decreased hemoglobin, and increased oxygen consumption.⁴⁻⁷

This study was undertaken to examine these factors more closely by distinguishing mis-

matching of ventilation to perfusion from true shunt as a cause of postoperative hypoxemia, emphasizing the importance of age to the postoperative changes in distribution of ventilation.

Methods

Sixty-nine patients of either sex, scheduled for elective extrathoracic operations under general anesthesia, were chosen for study (table 1). Vital capacity, FEV₁, chest x-ray, pulse rate, blood pressure, and ECG were checked as routine preoperative tests. No patient had clinical evidence of cardiopulmonary disease preoperatively, and the body builds of all patients were within normal limits. All patients were classified as physical status I (ASA).

Arterial blood was sampled on the day before operation while the patient was in the supine position breathing room air and after 10 minutes of inhalation of 100 per cent oxygen, utilizing a Ruben nonrebreathing valve and a face mask. Blood samples were obtained anaerobically from the radial artery after infiltration of the skin with 1 per cent lidocaine. Arterial puncture was carried out without causing anxiety, because the purpose of the measurements had been fully explained to the patients and they had consented to blood sampling. P_{aO_2} , P_{aCO_2} , and pH were determined at 37 C by means of an IL 113-S1 blood-gas analyzer (Instrumentation Laboratory, Inc., Boston, Massachusetts) immediately after sampling.

Preoperative premedication consisted of secobarbital (Ional) or nitrazepam (Benzalin) and atropine given 60 to 90 minutes before induction of anesthesia. Anesthesia was induced with thiamylal, followed by succinylcholine (40-60 mg) to facilitate endotracheal intubation with a cuffed tube. Anesthesia was maintained with 50 per cent nitrous oxide, 50 per cent oxygen, and 0.5 to 1.0 per cent halothane, supplemented with muscle relaxants as

* Associate.

† Instructor.

‡ Professor.

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TABLE 1. Classification of Patients

	Number of Patients		Ages (Years)	
			Mean	Range
Upper abdominal operations				
Gastrectomy	11	} 19	58	32-76
Cholecystectomy	6			
Laparotomy	2			
Lower abdominal operations				
Hysterectomy	14	} 28	50	26-72
Prostatectomy	4			
Urinary tract	7			
Others	3			
Non-abdominal operations				
Orthopedic	7	} 22	47	14-83
External genital	6			
Others	9			
TOTAL		69	51	14-83

needed. Respiration was maintained manually with assisted or controlled ventilation. The effect of the muscle relaxant was antagonized with atropine and neostigmine at the end of operation, when a nondepolarizing agent was used. Reversal of muscle relaxant effects was determined by clinical signs, for example, ability to move the upper chest wall during inspiration, ability to breathe deeply, ability to grasp the fingers, and tidal volume, measured by the Wright respirometer in most patients. In some patients, twitch or tetanus response was tested by nerve stimulation. The duration of anesthesia was 182 minutes (mean). After emergence from anesthesia, every patient was observed in the recovery room.

When the patient was able to respond to commands and vital signs were stable, the postoperative measurements were done during breathing of room air and oxygen. These measurements were made in the recovery room, usually one to two hours after operation. Narcotic medication was not given until these studies had been completed. Neither severe shivering nor marked deviation from normal body temperature was present during these measurements.

NITROGEN-WASHOUT STUDIES

Distributions of inspired gas before and after anesthesia were also compared in 20 of the 69

patients. The mean age of these patients (55 years) was slightly greater than the mean age of the entire group (51 years). Operative sites were similar to those of the other 49 patients (upper abdominal 4, lower abdominal 9, non-abdominal 7). The duration of anesthesia was 161 minutes (mean). Uniformity of distribution of the inspired gas was measured by the open-circuit multiple-breath nitrogen-washout method of Fowler.⁸

The preanesthetic measurements were made the day before anesthesia, with the patient supine and breathing spontaneously. The patient was fitted with a nose-clip and breathed through a rubber mouthpiece connected to the respiratory valve with a three-way stopcock which allowed either inspiration of room air and expiration to the atmosphere or inhalation of 100 per cent oxygen and exhalation through a Wright respirometer into a Douglas bag. The patient was instructed to breathe room air normally through the mouthpiece; after a period of adjustment, the selector knob on the three-way stopcock was turned at the end of an expiration so that 100 per cent oxygen was inhaled. Nitrogen washout was continued until end-tidal nitrogen had declined to a minimal, stable level. A part of the expired gas was continuously withdrawn through a sampling tube at the airway 2 cm distal to the lips and analyzed continuously by a ni-

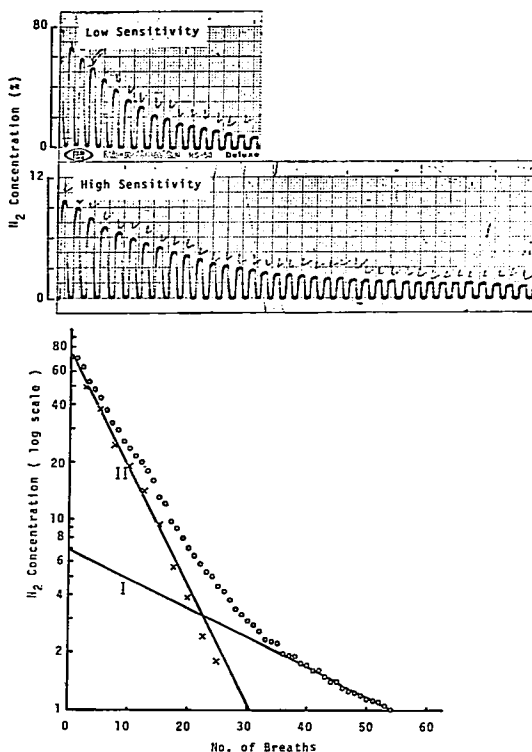


FIG. 1. Representative tracing of nitrogen-washout measurement (upper) and its graphic analysis (lower). The nitrogen-washout curve (open circles) was analyzed into two exponential components. Line I was obtained by extrapolating the terminal portions of the washout curve to zero. Line II was obtained by subtracting line I from the dotted curve. (For details of these calculations see Fowler *et al.*⁹)

trograph (Type 127, Godart N.V. De Bilt-Holland) calibrated with room air and 100 per cent oxygen. The output of the nitrograph was recorded continuously by a Godart pen-recorder.

The nitrogen-washout curve was obtained by plotting the end-expiratory nitrogen concentrations against the numbers of breaths on semilogarithmic graph paper.⁹ The nitrogen-washout curves were resolved into their com-

TABLE 2. Arterial Blood Gas Tensions in 69 Patients (Mean \pm SD)

	PaO ₂ (mm Hg)			PaCO ₂ (mm Hg)		
	Pre-operative	Post-operative	Change	Pre-operative	Post-operative	Change
Breathing room air	84 \pm 10.0	75 \pm 13.3	-9 \pm 12.8*	34 \pm 4.1	34 \pm 5.6	+0.8 \pm 4.7
Breathing 100 per cent oxygen	525 \pm 61.6	447 \pm 69.9	-77 \pm 68.5*	34 \pm 5.3	35 \pm 5.9	+1.0 \pm 5.7

* Statistically significant, $P < 0.05$.

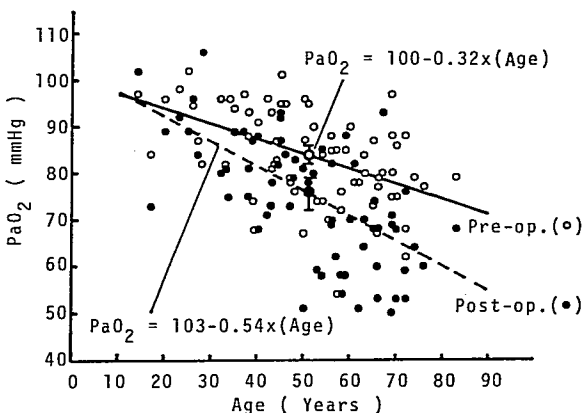


FIG. 2. Relationship between P_{aO_2} and age during breathing of room air.

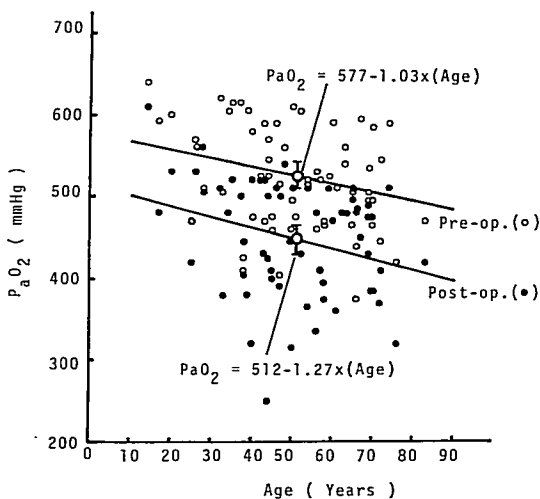


FIG. 3. Relationship between P_{aO_2} and age during breathing of 100 per cent oxygen.

ponents by graphic analysis by extrapolation. The data were analyzed by the method of Fowler and Lundin. The degree of uneven

distribution of inspired gas was expressed as percentage of nitrogen clearance delay, calculated by

$$\frac{\text{Actual average number of breaths} - \text{ideal average number of breaths}}{\text{Ideal average number of breaths}} \times 100$$

TABLE 3. Postoperative P_{aO_2} Decreases in Relation to Type of Operation (Mean \pm SD)

	Number of Patients	P_{aO_2} (mm Hg)			P_{aCO_2} (mm Hg)			P_{aO_2} (mm Hg)		
		Preoperative	Postoperative	Change	Preoperative	Postoperative	Change	Preoperative	Postoperative	Change
Breathing room air	10	53 \pm 12.0	69 \pm 8.6	-10 \pm 8.4	35 \pm 3.7	35 \pm 5.4	-0.1 \pm 5.7	35 \pm 3.7	35 \pm 5.4	-0.1 \pm 5.7
	28	53 \pm 10.0	70 \pm 13.0	-6 \pm 13.6	33 \pm 3.6	32 \pm 4.7	-0.2 \pm 4.3	33 \pm 3.6	32 \pm 4.7	-0.2 \pm 4.3
	22	55 \pm 8.7	78 \pm 15.5	-7 \pm 12.0	34 \pm 4.9	37 \pm 6.1	+2.7 \pm 3.5	34 \pm 4.9	37 \pm 6.1	+2.7 \pm 3.5
Breathing 100 per cent oxygen	10	521 \pm 60.9	454 \pm 60.6	-67 \pm 63.3	30 \pm 6.4	37 \pm 5.8	+7.0 \pm 5.0	30 \pm 6.4	37 \pm 5.8	+7.0 \pm 5.0
	28	517 \pm 66.5	443 \pm 74.0	-75 \pm 76.0	34 \pm 4.5	33 \pm 4.0	-0.3 \pm 4.8	34 \pm 4.5	33 \pm 4.0	-0.3 \pm 4.8
	22	538 \pm 62.8	448 \pm 78.8	-90 \pm 62.4	34 \pm 5.4	30 \pm 6.5	-4.0 \pm 5.8	34 \pm 5.4	30 \pm 6.5	-4.0 \pm 5.8

A representative tracing and its graphic analysis are shown in figure 1. The reproducibility of the nitrogen-washout curve was checked by a model lung.

Postoperative measurements were made at the time the postoperative blood-gas analyses were done. Functional residual capacity was also measured as a byproduct of the nitrogen-washout measurements.

Results

Results of blood-gas studies are summarized in table 2. Mean P_{aO_2} 's after anesthesia decreased consistently with inhalation of either room air or 100 per cent oxygen. There was no significant difference between pre- and postoperative P_{aCO_2} 's. P_{aO_2} values were plotted against age; the resulting regression lines and equations are shown in figures 2 and 3.

During breathing of room air, the significant negative correlation between P_{aO_2} and age was expressed as:

$$\text{Preoperative } P_{aO_2} = 100 - 0.32 \times \text{age} \\ (r = -0.52; P < 0.01)$$

$$\text{Postoperative } P_{aO_2} = 103 - 0.54 \times \text{age} \\ (r = -0.64; P < 0.01)$$

P_{aO_2} 's declined as age increased, and the slope of the regression line after anesthesia was significantly steeper ($P < 0.01$) than the slope before anesthesia.

During inhalation of 100 per cent oxygen the same significant correlation was expressed as:

$$\text{Preoperative } P_{aO_2} = 577 - 1.03 \times \text{age} \\ (r = -0.35; P < 0.05)$$

$$\text{Postoperative } P_{aO_2} = 512 - 1.27 \times \text{age} \\ (r = -0.27; P < 0.05)$$

There was no significant difference between the slopes of the regression lines during inhalation of oxygen before and after anesthesia ($P > 0.05$).

Table 3 lists the postoperative reductions in P_{aO_2} , classified according to site of operation. Three regression lines, one for each site of operation, were drawn between postoperative P_{aO_2} during breathing of room air and age

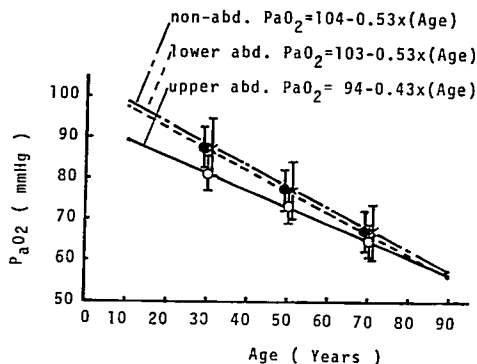


FIG. 4. Relationship between postoperative PaO_2 reduction classified according to the site of operation and age during breathing of room air.

(fig. 4). These were analyzed to distinguish between decreases in PaO_2 due to aging and decreases related to site of operation. Comparison of PaO_2 's at 30, 50, and 70 years of age obtained from these three regression lines disclosed no significant difference among the three groups. These results indicate that the sites of operation did not affect degree of postoperative hypoxemia in this series of experiments.

Table 4 shows nitrogen-washout results for the 20 patients so tested before and after anesthesia. The preanesthetic control value for nitrogen clearance delay was 35 per cent. This value increased significantly, to 70 per cent, after anesthesia. The relationship of the percentage difference between pre- and post-anesthetic nitrogen clearance delays to age was expressed as a significant regression line (fig. 5). The reduction in FRC after anes-

thesia was not significant. The relationship of the percentage difference between pre- and postanesthetic FRC's to age was expressed as a significant regression line (fig. 6).

Discussion

A significant negative correlation between preanesthetic PaO_2 during breathing of room air and age has been reported by many authors.¹⁰ Nunn¹¹ and Marshall¹² found similar negative correlations in postoperative patients, but they did not compare the same patients in the pre- and postoperative periods. In our study, a negative correlation was obtained before anesthesia, and a further decline of PaO_2 , also correlated with age, was found in the same patients in the immediate postoperative period during breathing of room air and 100 per cent oxygen. All the increases in the slopes of the postoperative regression lines in-

TABLE 4. Results of Nitrogen-Washout Studies (Mean \pm SD)

20 Patients (Ages 55 \pm 12 years)			
Upper abdominal operations 4	Lower abdominal operations 9	Non-abdominal operations 7	Total 20
	Preoperative	Postoperative	Difference
Nitrogen clearance delay (per cent)	35 \pm 11*	70 \pm 57*	+37 \pm 58
Functional residual capacity (ml)	1842 \pm 550	1626 \pm 470	-216 \pm 360
PaO_2 , room air, (mm Hg)	79 \pm 11*	68 \pm 13*	-11 \pm 13

* Statistically significant, $P < 0.05$.

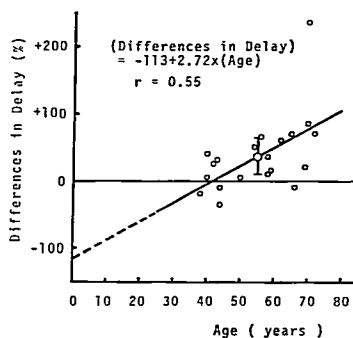


FIG. 5. Differences between pre- and postanesthetic nitrogen clearance delay percentages related to age (difference = postoperative value—preoperative value).

dicating that hypoxemia increases with increasing age; this does not differentiate the amount of increase resulting from true shunt from that resulting from mismatching of \dot{V}_a/\dot{Q} , by only blood-gas analysis, since there has been no real quantitation of the contributions of true shunt and \dot{V}_a/\dot{Q} mismatching to postoperative hypoxemia. The decrease in P_{aO_2} during breathing of room air is caused by both true shunt and mismatching of \dot{V}_a/\dot{Q} , but during inhalation of 100 per cent oxygen it is attributable to true shunt.¹³ An increase in the amount of true shunt after anesthesia was assumed because of the decrease in P_{aO_2} during inhalation of oxygen. The difference between the pre- and postoperative P_{aO_2} data correlated with age was less during breathing of oxygen than during breathing of room air, according to the difference between the slopes with air (-0.32 vs. -0.54 , a 70 per cent increase, statistically significant) and with oxygen (-1.03 vs. -1.27 , a 23 per cent increase, not significant). These findings suggest that true shunt increases in all patients postoperatively, regardless of age, and that the additional effect of \dot{V}_a/\dot{Q} abnormally becomes increasingly apparent postoperatively with advancing age.

We examined the effect of age on uneven ventilation in the early postoperative period by the nitrogen-washout measurement. Dis-

tribution of inspired gas has been analyzed by the technique of clearance of inert gas,^{8,14} which describes overall efficiency of the lung in mixing inspired gas, and by radioactive isotope studies,¹⁵ which describe regional distribution. There have been several reports of changes in the distribution of ventilation as studied by nitrogen-washout measurement during or after anesthesia. The mean values reported for nitrogen clearance delay in conscious subjects breathing spontaneously are: 21 per cent (mean age 25.4 years)⁸; 45 per cent (mean age 64 years) by Fowler⁸; 43 per cent (mean age 59 years) by Bergman.¹⁶ In our study, this value was 35 per cent in patients with a mean age of 55 years. It is important to note that there are limits inherent in the graphic analysis of the nitrogen-washout curve, in that this method of analysis of the exponential curve contains a subjective element. Bergman found no significant changes in uniformity of distribution of ventilation as measured by the open-circuit nitrogen-washout method in anesthetized patients breathing spontaneously and mechanically ventilated,

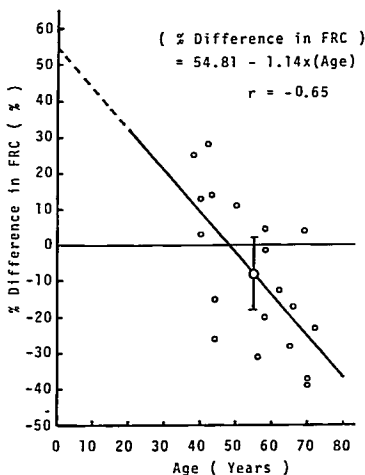


FIG. 6. Relationship of the difference between pre- and postanesthetic FRC values, in percentages, to age (difference = postoperative value—preoperative value).

compared with spontaneous breathing in the unanesthetized state. Okinaka¹⁷ demonstrated closure of the pulmonary air spaces following abdominal surgery on the first postoperative day; the air spaces returned to normal when the patient had recovered fully from the operation and was ambulatory. Okinaka used the two-balloon open-circuit nitrogen-washout method described by Emmanuel.¹⁷

In this study, the nitrogen clearance delay was significantly increased after anesthesia, and the increase was larger in older patients. These results coupled with those of the blood-gas studies indicate that there was impairment of overall gas mixing in the early postoperative period and that an increase of uneven ventilation with advancing age was one of the principal factors causing early postoperative hypoxemia.

Uneven distribution of ventilation may be produced by regional differences in pulmonary compliance and in airway resistance. Pulmonary compliance and airway resistance are altered by retention of secretions, changes in surfactant, pulmonary collapse due to absorption of the sequestered gases, changes in the distribution of pulmonary blood flow, tonus of bronchiolar smooth muscles, and changes in lung volume, during and after anesthesia. Recently, Jones¹⁸ explained the changes in the distribution of ventilation even in the supine position by a nonlinear pulmonary compliance curve. It was suggested¹⁹ that the less the lung volume, the less the elastic recoil, and the greater the chance for airway closure. Craig²⁰ showed the relationship of the difference between FRC and closing volume (measured by a modified single-breath nitrogen technique) to age. In the supine position, the relation was expressed as follows:

$$\text{FRC—closing volume} = 1681 - 47 \times \text{age}$$

According to this equation, the critical age at which airway closure in supine position starts to occur within tidal volume range is 36 years. Furthermore, from this equation, it was suggested that airway closure would be likely to occur as a result of the small decrease in FRC with increasing age. Although there was no significant change in mean FRC, the tendency for FRC to decrease in older subjects after an-

esthesia was demonstrated by a significant linear correlation in our study (fig. 6). Anesthesia might have altered the balance between the elastic recoil of the lungs and inspiratory muscle tone, leading to small reductions in lung volume, especially in older patients. A decrease in lung volume will reduce the diameter of the dependent airways or reduce compliance of the dependent part of the lungs, resulting in uneven distribution of inspired gas.²¹⁻²³ These changes are most likely to occur in the elderly.

Usually, early postoperative hypoxemia will not affect the postoperative course. On the other hand, very severe hypoxemia, intractable to therapy, sometimes occurs in postcardiotomy patients and those who have respiratory failure and need long-term mechanical ventilation. In these patients, changes in cardiac output, or morphologic and histochemical changes in the lungs, may also be factors in impairing oxygenation.

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CNS Function

EPIDURAL PRESSURE IN NEUROSURGERY Supratentorial epidural pressure (EDP) was recorded continuously for as long as 29 days in patients undergoing posterior fossa surgery, by implanting a miniature pressure transducer via a frontoparietal burrhole. A change from supine to the sitting position lowered EDP markedly; flexing the neck re-elevated it. Small adjustments of neck flexion usually lowered EDP again without compromising the surgical approach. In the sitting position, extreme hip flexion sharply increased both EDP and central venous pressure (CVP). The prone position also elevated both EDP and CVP. Both values returned toward normal, however, with proper support under the shoulders and pelvis and proper adjustment of neck flexion. Ventricular drainage acutely lowered EDP in all patients who had not previously had ventriculovenous shunts, but this effect appeared to be transient. In patients with increased intracranial pressure, craniectomy had no significant decompressive effect, but splitting the dura promptly lowered EDP. Hyperventilation lowered EDP. Data for acid-base balance or airway pressures used during ventilation were not reported. (*Nornes, H., and Magnaes, B.: Supratentorial Epidural Pressure Recorded during Posterior Fossa Surgery, J. Neurosurg.* 35:541-549, 1971.)

ABSTRACTER'S COMMENT: The authors show that EDP and ventricular fluid pressure correlate linearly and closely. Ventricular pressure cannot be monitored during posterior fossa surgery because of the need for ventricular decompression. This study, in addition to presenting new instrumentation (the miniature pressure transducer), provides the basis for direct measurement of what until now has been clinically estimated, the "relaxation of the brain" during posterior fossa surgery. The transducer, being extradural, can be maintained in place postoperatively with little fear of infection, and provides an early warning of an increase in intracranial pressure.