PULMONARY FUNCTION IN THE SURGICAL PATIENT

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THE introduction of improved methods of spirometry and of relatively simple methods of measuring arterial oxygen saturation and the blood gas tensions, has stimulated much research recently into disturbances of pulmonary function in the surgical patient. In this paper the effect of anaesthetic drugs and operative procedures on a number of aspects of pulmonary function will be considered, and the significance of these findings in the prevention and treatment of pulmonary complications after operations will be discussed.

First, some relevant aspects of the physiology of respiration will be reviewed.

Introduction

The function of respiration is to arterialise venous blood and maintain the partial pressures of oxygen and carbon dioxide in the arterial blood within narrow limits throughout a wide range of physiological activity. To accomplish this, ventilation must add oxygen to and remove carbon dioxide from alveolar gas at a rate determined by the metabolic requirements without the expenditure of excessive work. To achieve rapid gas exchange there must be no barrier to the diffusion of gases across the alveolar membrane, pulmonary blood flow must be adequate, and the distribution of the pulmonary blood must approximately equal the ventilation pattern throughout the lung.

Adequacy of Ventilation

This depends not only upon the volume of air passing the lips per minute (minute ventilation) because about a third of the tidal volume remains in the conducting airways (anatomical dead space) and does not take part in gas exchange. In addition, as a result of disturbed pulmonary function there may be alveoli which are inadequately perfused with blood and they will therefore also not partake fully in gas exchange (alveolar dead space). The anatomical and alveolar dead spaces together constitute the physiological dead space. In health, the anatomical and physiological dead spaces are

approximately equal, but in many disorders of the lungs the volume of the physiological dead space exceeds the anatomical because there is an appreciable alveolar dead space. If the partial pressure of carbon dioxide in expired gas ($P_{E\text{CO}_2}$) and arterial blood ($P_{a\text{CO}_2}$) and the tidal volume (V_T) are measured, the physiological dead space (V_D) can be calculated from Bohr's Equation and related to the tidal volume.

$$\frac{V_D}{V_T} = \frac{P_{a\text{CO}_2} - P_{E\text{CO}_2}}{P_{a\text{CO}_2}} \quad (1)$$

Normally the ratio, physiological dead space: tidal volume does not exceed 0.3. If it is increased, parts of the lung are assumed to have ventilation to perfusion ratios above average.

Effective or alveolar ventilation is the tidal volume minus the physiological dead space $\times$ the frequency of breathing. The level of alveolar ventilation is adjusted through the respiratory centre to maintain the carbon dioxide tension of arterial blood near 40 mm.Hg. If the alveolar ventilation is halved the arterial P_{CO_2} is doubled and if the alveolar ventilation is doubled the arterial P_{CO_2} is halved.

$$\text{Arterial } P_{\text{CO}_2} = \frac{\text{Vol. of } \text{CO}_2 \text{ excreted} \times \text{barometric pressure}}{\text{Alveolar ventilation}} \quad (2)$$

Thus, measurement of the arterial P_{CO_2} is a sensitive indication of the rate of alveolar ventilation.

If the arterial P_{CO_2} level rises above 44 mm.Hg. ventilatory failure is present (unless the raised P_{CO_2} level is compensatory in the presence of a primary non-respiratory or metabolic alkalosis).

Ventilatory failure is followed by a fall in arterial pH (respiratory acidosis) and when breathing air, by the development of arterial desaturation and hypoxaemia.

As the arterial P_{CO_2} rises and the pH falls, bicarbonate is retained by the kidney which will tend to restore the arterial pH level to normal (compensated respiratory acidosis). This

is apparent from the Henderson-Hasselbalch Equation.

$$\text{pH} = 6.1 + \log \frac{(\text{HCO}_3)^-}{0.03 \times \text{PaCO}_2} \quad (3)$$

Although hypercapnia (raised arterial Pco_2) does not result from lung disease without there being reduced alveolar ventilation, arterial desaturation may occur although alveolar ventilation is adequate due to uneven distribution of gas and blood within the lung (ventilation—perfusion imbalance), or more rarely because the transfer of oxygen across the alveolar membrane is impaired. (Carbon dioxide transfer is not affected because it is about 20 times more diffusible than oxygen.)

Central cyanosis cannot therefore be relied upon as an indication of inadequate ventilation and ventilatory failure can be diagnosed with certainty only when the arterial Pco_2 is measured. Moreover, it must be remembered that ventilatory failure and severe respiratory acidosis may be present in a pink patient who is breathing oxygen-enriched air as, for example, during anaesthesia.

Oxygenation of Arterial Blood

The arterial oxygen tension depends on, first, the tension of oxygen in the alveoli; secondly, whether there is any barrier to the diffusion of oxygen through the alveolar membrane and into the red cells, and thirdly, the degree of venous admixture or shunt effect due to blood coming from areas of lung which are ventilated poorly or not at all, although adequately perfused with pulmonary capillary blood. In addition blood from bronchial, pleural and Thebesian veins by by-passing the pulmonary capillaries contributes to the venous admixture effect.

The alveolar Po_2 depends upon the inspired Po_2 , the alveolar Pco_2 and the respiratory-exchange ratio. Because the volume of nitrogen is constant for inspired and expired gas and because the sum of the partial pressures of gases in the alveoli is equal to atmospheric pressure, the alveolar Po_2 can be readily calculated from the alveolar-air equation which states that

$$\text{Mean Alveolar } \text{Po}_2 = \text{Inspired } \text{Po}_2 - \frac{\text{Arterial } \text{Pco}_2^*}{\text{Respiratory Exchange Ratio}} \quad (4)$$

*The arterial and alveolar Pco_2 tension are assumed to be equal.

In health, the alveolar-arterial O_2 tension difference is less than 10 mm.Hg.—most of this arises because of variations in regional ventilation to perfusion ratios especially in the erect posture, when blood from the lower lobes is less well oxygenated than that from other parts of the lung and so contributes to the venous admixture effect. In disordered pulmonary function these inequalities are often much increased and may give rise to significant hypoxaemia.

Barriers to diffusion across the alveolar membrane become important in the production of hypoxaemia when the alveolar Po_2 is reduced. Although O_2 transfer across a thickened alveolar membrane may be impaired on exercise when the alveolar Po_2 is normal because the rate of diffusion is less, diffusional impairment is seldom important clinically at rest if the alveolar Po_2 is normal.

Mechanical Factors in Breathing

Inspiratory muscular contraction is required to overcome the elastic forces of the lungs and thorax and the resistance to airflow through the bronchial airways. Expiration is passive in the absence of airway obstruction. The main muscles of inspiration are the diaphragm and to a lesser extent the intercostal muscles. The efficiency of the bellows action of the chest can be assessed by measuring the Vital Capacity (VC) which is the volume of gas that can be breathed out after a maximal inspiration, without any restriction as to time. It depends upon the inspiratory muscle power, the mobility of the thorax and the distensibility of the lungs. A reduction in Vital Capacity therefore indicates mainly a restrictive ventilatory defect. The amount of gas that can be expired after a maximal inspiration in a given time is a sensitive indicator of obstruction of the bronchial airways. The volume expired in one second is the Forced Expiratory Volume in 1 sec. (FEV_1). Alternatively the Peak Expiratory Flow Rate (PEFR) in litres per minute may be measured.

In pure restrictive ventilatory insufficiency the VC and FEV_1 are both reduced, but the ratio $\frac{\text{FEV}_1}{\text{VC}}$ is, as in health, greater than 75 per cent. Where there is airway obstruction this ratio is reduced and in severe cases it may be less than 40 per cent. The amount of obstructive ventilatory defect due to reversible airway obstruction can be determined by measuring the FEV_1 before and after the aerosol inhalation of a bronchodilator drug such as 1 per cent isoprenaline. Reversible airway obstruction is

indicated by an absolute increase in FEV_1 (rather than increases in $\frac{FEV_1}{VC}$ ratios).

At the end of a normal quiet expiration, the amount of air in the lungs is the Functional Residual Capacity (FRC). At the position of full expiration i.e. after the vital capacity has been exhaled, airway closure occurs, and the gas then remaining in the lung which cannot be exhaled is the residual volume (RV). The Vital Capacity and the Residual Volume make up the total lung capacity (TLC). If the TLC is reduced, the VC is reduced also, but the VC may be reduced because the RV is increased, as for example, when the lungs are overinflated. When the FRC is reduced, the VC and TLC will also be reduced, breathing is more in the expiratory or deflated position and small airway closure may occur even at the resting respiratory level.

Effects of Anaesthesia and Surgical Operations on Pulmonary Physiology

Ventilatory Function

Impaired alveolar ventilation due to the depressant effects of the anaesthetic on the respiratory centre may occur during and briefly immediately after operations when breathing is spontaneous but not when it is controlled (Dundee, 1952; Hobsley, 1963). Where abdominal incisions have been made there is a persisting restrictive impairment of pulmonary mechanical function due mainly to reduced diaphragmatic movement which is greatest during the first two postoperative days and persists for many days afterwards. The Vital Capacity is reduced to less than half the pre-operative level, and the Forced Expiratory Volume in 1 sec. and Peak Expiratory Flow Rate are similarly reduced (Palmer, 1961; Palmer and Gardiner, 1964). The total lung capacity is reduced and there is a consistent and significant decrease in functional residual capacity (Beecher, 1933 b) so that the patient is breathing in a more expiratory position than normal. The tidal volume is reduced but the respiratory rate is increased so there is little or no change in Minute Volume (Beecher, 1933a; Palmer and Gardiner, 1964). The normal pattern of breathing is altered, however, being at a low and fixed tidal volume with an absence of periodic deep breaths. This may lead to a fall in lung compliance, and to progressive alveolar atelectasis, an effect which can be prevented by periodic hyperinflation of the lungs (Bendixen, Hedley-Whyte and Laver, 1963).

The impairment of pulmonary function is

more marked after upper than lower abdominal operations and occurs whether or not postoperative bronchopneumonia occurs. Those in whom this complication develops show a somewhat greater restrictive ventilatory defect than normals and they often show in addition reversible airways obstruction during the first three postoperative days as shown by absolute increases in FEV_1 and PEFR after the inhalation of a bronchodilator drug (Palmer, 1961; Palmer and Gardiner, 1964).

Fig. 1 shows measurement of FEV_1 before and after gastric surgery in two groups of patients—one was uncomplicated but the other developed postoperative bronchopneumonia. FEV_1 was recorded at daily intervals before (interrupted lines) and after (continuous lines) aerosol inhalation of isoprenaline. In those who subsequently developed bronchopneumonia there was a slight increase in FEV_1 before the operation after the bronchodilator indicating some reversible airways obstruction. After the operation there was a considerable reduction in FEV_1 in both groups; this was maximal on the first postoperative day and gradually became less marked afterwards. The reduction in FEV_1 was greater in those who developed bronchopneumonia and in these patients there was a mean increase of FEV_1 after the bronchodilator during the first three postoperative days. This was especially marked in the subjects with the most severe chest complications.

It is apparent therefore that laparotomy has a profound effect on pulmonary mechanical function leading to a marked restrictive ventilatory defect, and breathing that is shallow, rapid, at a fixed tidal volume predominantly in the expiratory position, and lacking in periodic deep breaths. In those who develop bronchopneumonia these changes are more marked and they may also show reversible airway obstruction during the first three postoperative days.

Blood Gas Tensions and Acid-Base Balance

Carbon Dioxide

Hypercapnia sometimes occurs during and immediately after operation when breathing is spontaneous and unassisted. For example in patients undergoing uterine dilatation and curettage the mean arterial P_{CO_2} level rose from a control value of 40 mm.Hg. to 55 mm.Hg. during the anaesthetic, falling to 45 mm.Hg. an hour afterwards (Taylor, Scott and Donald, 1964). However, these patients were operated upon in the lithotomy position and it seems that this position during operation rather than

FIG. 1.— FEV₁ mls. (BPTS) before and after gastric surgery

the effect of the anaesthetic was responsible for the production of slight alveolar hypoventilation. The development of hypercapnia is not inevitable either during or immediately after surgical procedures under general anaesthesia. In a group of patients undergoing carotid angiography and other minor surgical operations when breathing was spontaneous, no significant change in arterial CO₂ tension levels from the control measurements was found (Gardiner and Palmer, 1964). On the other hand, when breathing is controlled during the anaesthetic patients are often somewhat hyperventilated leading to a fall in arterial Pco₂ levels and hypocapnia. Thus, with modern anaesthesia, skilfully administered, any effect on the arterial carbon-dioxide tension is slight and short-lived.

After abdominal incisions have been made there is a marked restrictive impairment of pulmonary ventilatory function and the pattern of breathing is altered, but, in spite of this, slight hypocapnia rather than hypercapnia is found postoperatively. After gastric surgery, for example, the mean arterial Pco₂ fell from 38 mm.Hg. before the operation to 35 mm.Hg. on the second and third postoperative days. In those who developed postoperative bronchopneumonia the arterial Pco₂ level fell from a mean preoperative level of 40 mm.Hg. to 30 mm.Hg. on the 5th postoperative day—so that

these patients had a mild respiratory alkalosis (Palmer and Gardiner, 1964). These changes reflect the increased physiological dead/tidal volume ratios which have been measured after gastric surgery and which indicate the presence of areas of lung with high ventilation: perfusion ratios (probably at the upper parts of the lung) due to over-ventilation (Palmer, Gardiner and McGregor, 1965).

Hypocapnia develops postoperatively only in those patients in whom the arterial Pco₂ level is normal before the operation. In subjects with obstructive lung disease who have some degree of carbon dioxide retention, serious postoperative hypercapnia and respiratory acidosis may occur. This cannot be readily detected clinically and for the proper management of these patients measurement of the arterial Pco₂ level before and after the operation is essential.

Acid-Base Balance

A primary metabolic acidosis has been found after major operations especially when large doses of anaesthetic agents have been used and the operation has taken a long time. It is most commonly associated with a respiratory acidosis produced by depression of the respiratory centre by the anaesthetic drugs (Holaday, Ma and Papper, 1957; Hobsley, 1963). The cause of the metabolic acidosis is not clear and several fac-

tors are probably responsible such as the effects of trauma, of the anaesthetic, starvation and hypoxaemia. This combined metabolic and respiratory acidosis is short-lived, and a mild respiratory alkalosis is commonly found for some days after abdominal operations. This might result from anoxic stimulation of the carotid and aortic bodies but this is unlikely as the lowest arterial P_{CO_2} levels do not occur on the days postoperatively when the arterial P_{O_2} levels are most reduced. It probably results from alteration in the pattern of breathing leading to slight overall alveolar hyperventilation. The tendency to over-ventilation and hypocapnia is compensated for by the development of a mild metabolic acidosis the extent of which closely parallels the lowered P_{CO_2} levels (Palmer and Gardiner, 1964).

Oxygen

While it has been recognised for some time that arterial saturation commonly follows open chest surgery (Maier and Cournaud, 1943), it is only comparatively recently that arterial saturation has been reported during and immediately after other operations under general anaesthesia, and this arises whether breathing is spontaneous or controlled during the anaesthetic (Nunn and Payne, 1962; Conway and Payne, 1964). Nevertheless, this is not an invariable occurrence and no hypoxaemia has been found after carotid angiography or uterine dilatation and curettage under general anaesthesia when breathing was spontaneous (Gardiner and Palmer, 1964; Taylor and others, 1964). Apart from major thoracic and cardiac surgery muscular incisions are probably necessary for the development of significant postoperative hypoxaemia. After gastric surgery, for example, hypoxaemia constantly occurs and persists for at least five days. Falls in arterial P_{O_2} levels of about 20 mm.Hg. from preoperative values are commonly found on the first postoperative day and arterial P_{O_2} levels of 70 mm.Hg. or below (equivalent to an arterial saturation of 92 per cent) are usual when the arterial P_{O_2} levels are within the normal range beforehand. When postoperative bronchopneumonia develops arterial P_{O_2} levels as low as 55 mm.Hg. corresponding to an arterial O_2 saturation of 85 per cent may occur. Postoperative hypoxaemia is not due to overall hypoventilation, however, as it occurs in the absence of hypercapnia, nor does it strictly parallel the reduction in Vital Capacity and there is more usually slight overall hyperventilation leading to reduced arterial P_{CO_2} levels. There is a sig-

nificant correlation between the postoperative P_{O_2} and the age of the patient (Nunn, 1965) and a regression equation has been derived:

$$\text{Postoperative } P_{O_2} = 94.3 - 0.455 (\text{age})$$

There is, however, considerable scatter of P_{O_2} levels within any decade, which indicates that there is considerable variation in the factors which result in postoperative hypoxaemia.

It has been suggested that premedication might be a factor in the development of postoperative hypoxaemia as arterial desaturation was found after atropine and before the operation (Tomlin, Conway and Payne, 1964; Payne and Conway, 1966). However arterial saturation or reduced O_2 tensions have not been found when atropine is given to healthy volunteers (Daly, Ross and Behnke, 1963; Nunn and Bergmann, 1964) and in further experiments premedication with atropine or with papaveretum and scopolamine in surgical patients was not followed by a change in control arterial blood measurements—either arterial O_2 saturation or O_2 tension—both values being directly measured (Taylor, Scott and Donald, 1964; Gardiner and Palmer, 1964).

Recently total cardiopulmonary by-pass has been shown to be frequently complicated by postoperative hypoxaemia and in this instance it arises especially when homologous perfused blood is used, which it is suggested, leads to an immune reaction in the lungs. Congestion, thickening of the interalveolar walls, patchy collapse and intra-alveolar haemorrhage occur so that an appreciable portion of the cardiac output traverses the lungs without being oxygenated (Nahas, Melrose, Sykes and Robinson, 1965).

The combination of hypoxaemia without hypercapnia in surgical patients has been suggested to be due to an increased venous admixture effect from regional ventilation/perfusion inequality in the lungs and possibly also from shunting of pulmonary capillary blood through unventilated areas of alveolar collapse.

This hypothesis is supported by the observation that normal saturation is rapidly restored by breathing moderately enriched oxygen-air mixtures (which reverses the effect of regional alveolar hypo-ventilation) and by studies in which alveolar-arterial O_2 tension gradients were directly measured before and for five days after gastric surgery. These have shown that the hypoxaemia was associated with a proportionate increase in alveolar-arterial tension gradient (Palmer, Gardiner and McGregor, 1965)—an effect which may be equivalent to a right to left shunt of 25 per cent of the pulmonary blood

flow. Alveolar O_2 tensions were normal so that impaired diffusion is unlikely to play a part in the development of hypoxaemia. Because alveolar-arterial oxygen tension differences were greater when breathing 100 per cent oxygen after major abdominal surgery than before the operation the presence of shunts due to pulmonary collapse is also indicated (Gordh, Linderholm and Norlander, 1958). During anaesthesia also there is an increased alveolar-arterial O_2 tension difference and increased venous admixture which can largely be prevented when large tidal volumes are used during controlled ventilation (Sykes, Young and Robinson, 1965).

Thus, it seems that after operations where muscular incisions have been made there is reduced diaphragmatic movement and an inability to take periodic deep breaths. This leads to low ventilation/perfusion ratios at the lung bases and possibly to areas of alveolar collapse which may be present without X-ray evidence (Hamilton, McDonald, Fischer and Bethards, 1961).

The development of slight hypoxaemia is therefore almost inevitable after abdominal surgery but it becomes less marked as the restrictive ventilatory defect improves during convalescence and it is unlikely to be of much significance to patients in good health. But in older subjects (who start with lower PO_2 levels) and in those with cardiac and cerebrovascular disease it is of greater significance. Changes in blood gas tensions are of most importance to those with chronic respiratory diseases because there is commonly hypoxaemia with or without hypercapnia before the operation. They are also most prone to develop postoperative bronchopneumonia.

Postoperative Bronchopneumonia

This develops almost exclusively in patients with varying degrees of chronic bronchopulmonary disease, especially chronic bronchitis, who undergo abdominal surgery (Palmer, 1962). Bronchitics commonly have a restrictive ventilatory defect and reduced vital capacity with airway obstruction and reduced FEV_1 or $PEFR$, and are therefore less able to tolerate the changes in ventilatory function that occur after laparotomy. They have increased bronchial secretion, low grade pulmonary infection and depressed ciliary activity. The amount of bronchial secretion increases after the operation and, because coughing is impaired and ciliary activity further depressed, it cannot be expectorated. Small symptomless areas of pulmonary collapse which in the normal gradually re-expand, ex-

tend, giving rise to larger areas of segmental collapse which become infected leading to bronchopneumonia. This causes a worsening in the degree of hypoxaemia.

Aerosol inhalations of bronchodilators with assisted postural drainage (Palmer and Sellick, 1953) or intermittent positive pressure breathing with isoprenaline (Anderson, Dossett and Hamilton, 1963) overcome the restrictive ventilatory defect, reduce airway obstruction, and aid the expectoration of bronchial secretion. In these ways they prevent the start of a train of events which lead to postoperative pneumonia.

Because of the great importance of recognising the high-risk case, especially those with chronic obstructive lung disease, preoperative spirometry should be carried out in all patients about to undergo major abdominal surgery. Where abnormalities are found, blood gas tensions must also be measured. If these are abnormal, careful monitoring of blood gas tensions postoperatively is mandatory and, when dangerous hypoxaemia or hypercapnia develop, postoperative tracheostomy and oxygen therapy with or without assisted ventilation will be required. It is only by these measures that the morbidity and mortality from postoperative chest infection will be reduced.

Summary

With modern anaesthetics skilfully administered, there is little risk of serious hypo-ventilation and carbon dioxide retention during or immediately after even a major operation. Arterial desaturation is also not a problem during anaesthesia because oxygen is usually added to inspired gas, but an increased alveolar-arterial oxygen tension difference and increased venous admixture exist because of ventilation/perfusion imbalance in the lungs. The continuing effects of surgery on pulmonary function are almost wholly confined to operations where muscular incisions have been made. After laparotomy there is marked restrictive ventilatory impairment, breathing is rapid, shallow and predominantly in an expiratory position, and there is an inability to take deep breaths. These changes lead to hypoxaemia but without hypercapnia, due to an increased venous admixture effect from ventilation/perfusion inequality in the lungs and probably from true shunts through unventilated areas of alveolar collapse. While these changes are not important to the patient in good health, they are of great importance in older subjects and in those with chronic bronchopulmonary disease who are especially prone to develop postoperative bronchopneumonia.

These patients require preoperative spirometry and measurement of blood gas tensions before and after operation to detect alveolar hypoventilation and dangerous hypoxaemia.

REFERENCES

- ANDERSON, W. H., DOSSETT, B. E., and HAMILTON, G. L. (1963): Prevention of Postoperative Pulmonary Complications. Use of Isoproterenol and Intermittent Positive Pressure Breathing on Inspiration, *J. Amer. med. Ass.*, **186**, 763.
- BEECHER, H. K. (1933 a): The Measured Effect of Laparotomy on Respiration, *J. clin. Invest.*, **12**, 639.
- BEECHER, H. K. (1933 b): The Measured Effect of Laparotomy on Lung Volume, *J. clin. Invest.*, **12**, 651.
- BENDIXEN, H. H., HEDLEY-WHYTE, J., and LAVER, M. B. (1963): Impaired Oxygenation in Surgical Patients During General Anaesthesia with Controlled Ventilation, *New Engl. J. Med.*, **269**, 991.
- CONWAY, C. M., and PAYNE, J. P. (1964): Hypoxaemia Associated with Anaesthesia and Controlled Respiration, *Lancet*, **i**, 12.
- DALY, W. J., ROSS, J. C. and BEHNKE, R. H. (1963): The Effect of Changes in the Pulmonary Vascular Bed Produced by Atropine, Pulmonary Engorgement and Positive Pressure Breathing on Diffusing and Mechanical Properties of the Lung, *J. clin. Invest.*, **42**, 1083.
- DUNDEE, J. W. (1952): Influence of Controlled Respiration on Dosage of Thiopentone and d-Tubocurarine Chloride Required for Abdominal Surgery, *Brit. med. J.*, **ii**, 893.
- GARDINER, A. J. S., and PALMER, K. N. V. (1964): Effect of Premedication and General Anaesthesia on Arterial Blood Gases, *Brit. med. J.*, **ii**, 1443.
- GORDH, T., LINDERHOLM, H., and NORLANDER, O. (1958): Pulmonary Function in Relation to Anaesthesia and Surgery Evaluated by Analysis of Oxygen Tension of Arterial Blood, *Acta anaesth. scand.*, **2**, 15.
- HAMILTON, W. K., McDONALD, J. S., FISCHER, H. W., and BETHARDS, R. (1964): Postoperative Respiratory Complications. A Comparison of Arterial Gas Tensions, Radiographs and Physical Examination, *Anaesthesiology*, **25**, 607.
- HOBSLEY, M. (1963): Respiratory Disturbances Caused by General Surgical Operations, *Ann. roy. Coll. Surg. Engl.*, **33**, 1121.
- HOLADAY, D. A., MA, D., and PAPPER, E. M. (1957): The Immediate Effects of Respiratory Depression on Acid-Base Balance in Anaesthetized Man, *J. clin. Invest.*, **36**, 1121.
- MAIER, H. C., and COURNAND, A. (1943): Studies of the Arterial Oxygen Saturation in the Postoperative Period after Pulmonary Resection, *Surgery*, **13**, 199.
- NAHAS, R. A., MELROSE, D. G., SYKES, M. F., and ROBINSON, B. (1965): Post-Perfusion Lung Syndrome. Effect of Homologous Blood, *Lancet*, **ii**, 254.
- NUNN, J. F. (1965): Influence of Age and Other Factors on Hypoxaemia in the Postoperative Period, *Lancet*, **ii**, 466.
- NUNN, J. F. and BERGMANN, N. A. (1964): The Effect of Atropine on Pulmonary Gas Exchange, *Brit. J. Anaesth.*, **36**, 68.
- NUNN, J. F., and PAYNE, J. P. (1962): Hypoxaemia after General Anaesthesia, *Lancet*, **ii**, 631.
- PALMER, K. N. V. (1961): Changes in Ventilatory Function after Abdominal Operations, *Lancet*, **i**, 191.
- PALMER, K. N. V. (1962): The Aetiology, Diagnosis and Treatment of Postoperative Pulmonary Complications, *J. roy. Coll. Surg. Edinb.*, **7**, 110.
- PALMER, K. N. V., and GARDNER, A. J. S. (1964): Effect of Partial Gastrectomy on Pulmonary Physiology, *Brit. med. J.*, **i**, 347.
- PALMER, K. N. V., GARDNER, A. J. S., and MCGREGOR, M. H. (1965): Hypoxaemia after Partial Gastrectomy, *Thorax*, **20**, 73.
- PALMER, K. N. V., and SELICK, B. A. (1953): The Prevention of Postoperative Pulmonary Atelectasis, *Lancet*, **i**, 164.
- PAYNE, J. P., and CONWAY, C. M. (1966): Hypoxaemia after Surgery and Anaesthesia, *Postgrad. med. J.*, **42**, 341.
- SYKES M. K., YOUNG, W. E., and ROBINSON, B. E. (1965): Oxygenation during Anaesthesia with Controlled Ventilation, *Brit. J. Anaesth.*, **37**, 314.
- TAYLOR, S. H., SCOTT, D. B., and DONALD, K. W. (1964): Respiratory Effects of General Anaesthesia, *Lancet*, **i**, 841.
- TOMLIN, P. J., CONWAY, C. M., and PAYNE, J. P. (1964): Hypoxaemia due to Atropine, *ibid*, **i**, 14.