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THE CONTROL OF SUPPLEMENTAL OXYGEN BY OXIMETRY*

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THE NEWBORN PREMATURE INFANT in respiratory distress is menaced by two dangers. Firstly, there is the danger of damage to vital centres entailed in hypoxia.[1] Secondly there is the possibility of retrolental fibroplasia following on an unnecessarily high partial pressure of oxygen in arterial blood (PaO_2) from unduly high and long continued inspired oxygen concentrations.[2–10] A control method is therefore required to ensure that inspired oxygen concentration conforms to the requirement of the infant.

This paper describes experience in the control of supplemental oxygen by a diamagnetic oxygen analyser and a Wood ear oximeter. The investigation was aimed primarily at establishing the feasibility of the method. No specific weight group was observed and no attempt is made to draw statistical conclusions from the series, since the numbers involved are too small. However, some observations on the required duration of therapy and concentrations of oxygen have been made and will be discussed.

Apparatus

The Wood ear oximeter registers photo-electrically the transmission of light in the visible red (640 millimicrons) and near infra-red (800 millimicrons) wave bands by blood in the heat-flushed ear with varying relative percentages of oxyhæmoglobin and total hæmoglobin.[11] The ratio of transmission in the visible red to that in the infra-red is a function of the arterial oxygen saturation (SaO_2). By bucking output of the two photocells of the earpiece against each other a continuous reading of arterial oxygen saturation is obtained which has been shown to be within 5% of simultaneous samples of arterial blood analyzed by the van Slyke technique.[11–13] It is important for accuracy that the peripheral circulation through the ear be adequate and the capillary blood fully arterialized in the pinna by heat generated from the earpiece light source. Below 75% arterial saturation the error of the method increases progressively to reach a standard deviation from the mean of the order of 10% from simultaneous van Slyke analyses at an arterial oxygen saturation of 60%.

The diamagnetic oxygen analyser is now standard equipment and need not be discussed further. The model used had an accuracy of plus or minus 1%.*

Method

The earpiece is applied to the infant's ear while in the isolette and the effect of varying atmospheric oxygen concentration within the isolette on arterial oxygen saturation is recorded. The least concentration of oxygen that will maintain a normal 95-98% arterial saturation is found by trial. Serial daily observations are made as far as possible, until it is found that the infant maintains a normal arterial oxygen saturation in air.

RESULTS

The 31 patients investigated were receiving supplemental oxygen on clinical grounds without prior knowledge of the oximetry results. The indications for oxygen were cyanosis of presumed central origin or dyspnœa or both.

TABLE I.—INITIAL ARTERIAL OXYGEN SATURATIONS IN 15 DESATURATED CASES WITH THE REQUIRED MINIMUM INSPIRED OXYGEN LEVELS FOR NORMAL SATURATION.

Case	*% Arterial oxygen saturation at first, examined in air unless otherwise stated*	*Required O_2 concentration % to raise arterial O_2 saturation to 95%*
Wi.	67 in 27% O_2	59 for 89% SaO_2
Al.	51	59
Br.	<63	50
Re.	88 in 29%	48
St.	50	42 for 92% SaO_2
Wa.	89.5	31
Vi.	83	30
Wis.	81.5	30
An.	91	29
To.	84	28
Bro.	81	27
Gl.	87.5	26
Pe.	88	26
Sc.	<40	Not known

In 14 patients receiving supplemental oxygen on clinical grounds, arterial oxygen saturations were above 95% when they were removed from oxygen and tested in air. However, none of these

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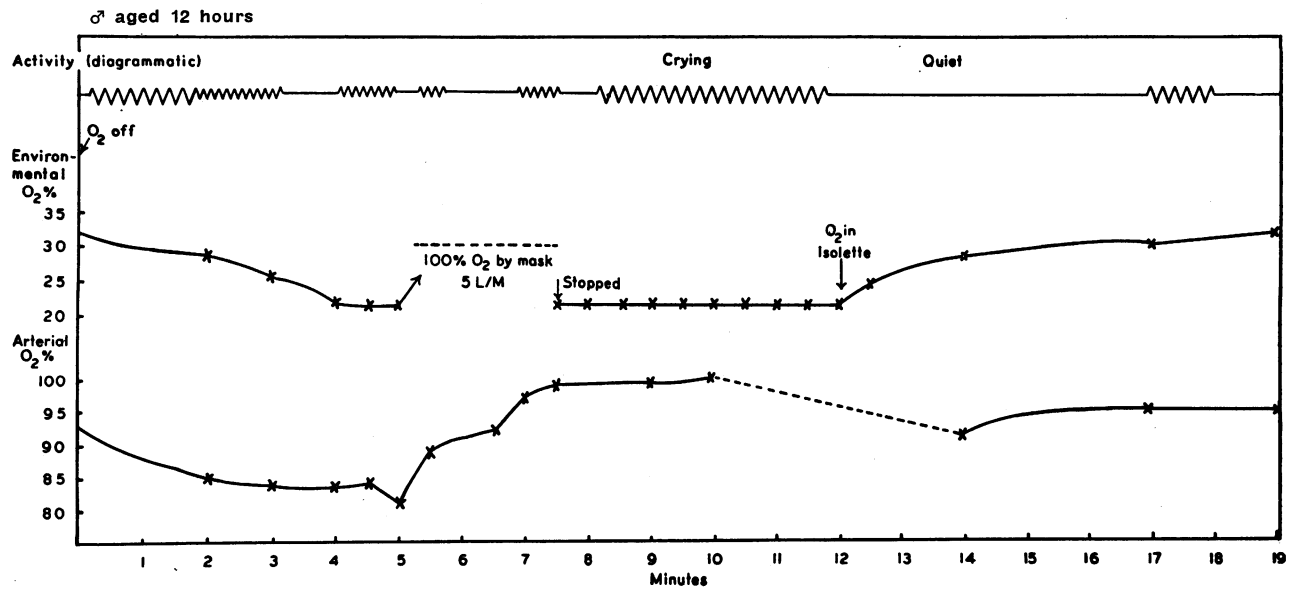

Fig. 1.—Birth weight 5 lb. 2 oz. The effect of supplemental oxygen on SaO_2. Note that at the end of the record a normal SaO_2 is maintained with approximately 30% ambient O_2.

infants had a birth weight of under 4 lb. and none was receiving over 35% oxygen. These infants were therefore unlikely candidates for retrolental fibroplasia, but were probably receiving oxygen unnecessarily. Two infants were moribund and in profound peripheral circulatory failure. Under these circumstances the circulation through the ear did not become arterialized in response to the heat of the earpiece light source. The method is therefore useless in such cases.

In one case, the blood was desaturated in air at the first examination, but the required level of oxygen for normal saturation could not be determined owing to technical difficulties. However, this patient achieved 89% saturation with 59% supplemental oxygen.

In 14 cases there was less than 95% saturation at their first examination. Table I gives the arterial oxygen saturation at the first examination and the percentage concentration of supplemental oxygen required (see also Fig. 6). The figures show that a significant proportion of cases required more than 40% oxygen initially to achieve an approximately normal arterial oxygen saturation (six out of 15). Five died, though in one the cause of death was unrelated to respiratory failure. With one exception, which will be discussed later, no surviving infant required supplemental oxygen for

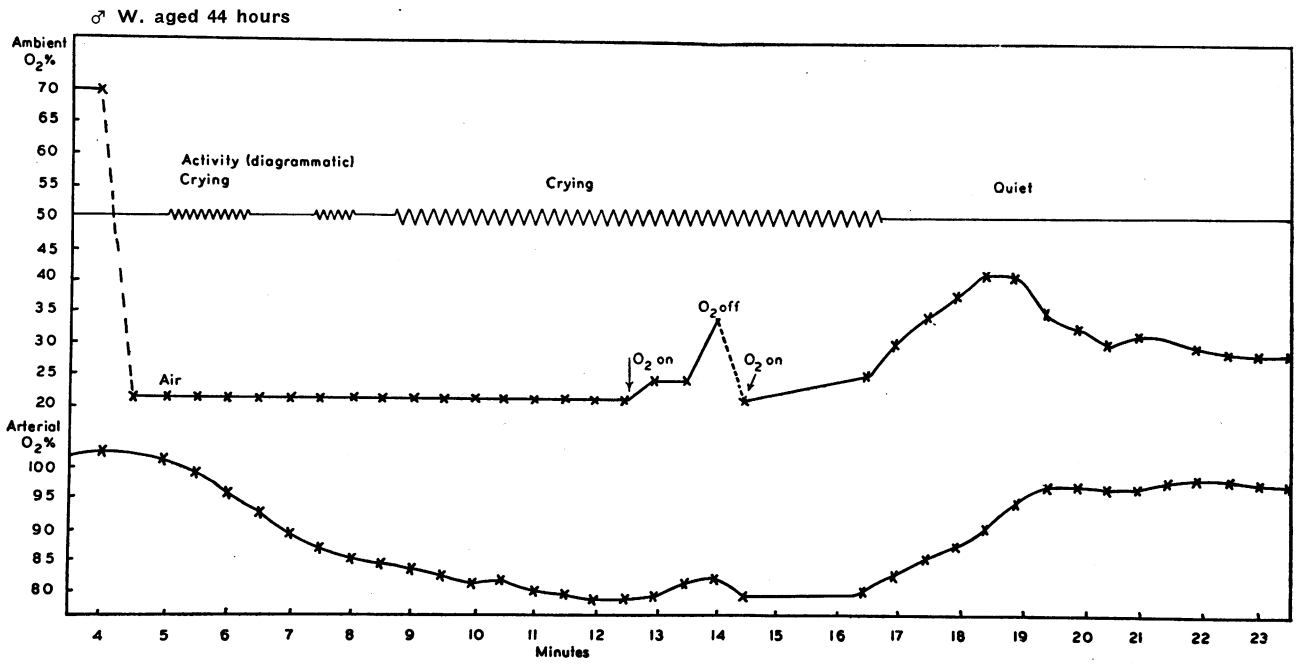

Fig. 2.—The same infant at 44 hours still shows arterial desaturation breathing air, but SaO_2 is again restored to normal by 30% O_2 at the end of the record.

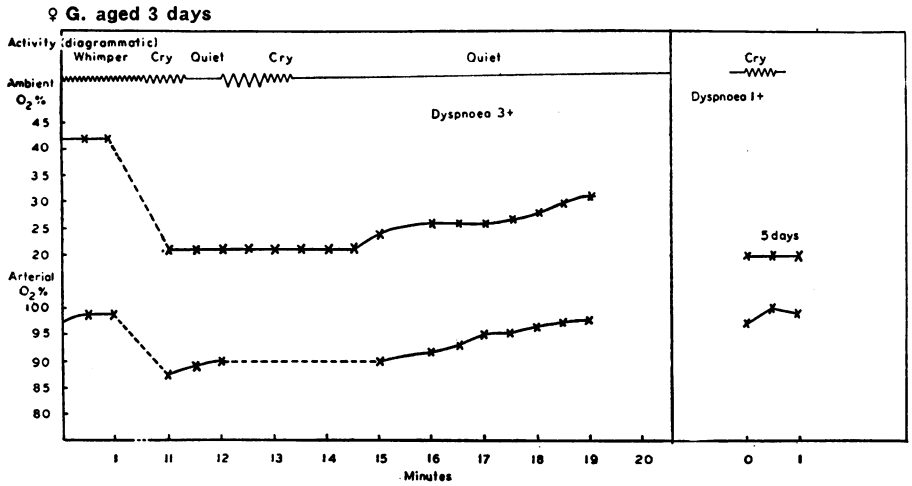

Fig. 3.—This infant shows arterial oxygen desaturation on the third day when placed in air, but normal saturation in air on the fifth day.

longer than five days. The tendency was for the requirement for supplemental oxygen to diminish progressively with the passage of time (Fig 7).

One infant requiring oxygen for longer than five days was proven by angiocardiography on the second day of life to have a persistent patency of the ductus arteriosus with reversal of flow. This infant had a lower arterial oxygen saturation with the earpiece on the scrotum than was registered with the earpiece on the ear during the first eight days of life. The degree of desaturation on the ear was not clinically significant after eight days. Further examination at two months disclosed a normal arterial oxygen saturation on the ear and no clinical, radiological or electrocardiographic signs of cardiac or pulmonary anomaly.

Discussion

Control of supplemental oxygen by measurement of arterial oxygen saturation depends on the ability of the ear oximeter to detect deviations both below and above the normal saturation level.

Below normal, changes in saturation are quite large in relation to changes in arterial oxygen tension, as the steep slope of the oxygen hæmoglobin dissociation curve in this area indicates. There is therefore no difficulty in detecting arterial desaturation oximetrically.

Above normal, the changes in saturation are small in relation to tension changes, as the oxygen hæmoglobin dissociation curve is almost flat in this area. It is this problem which requires further discussion in relation to the validity of the method of oximetric control.

Fowler and Comroe[14] have analyzed oxygen tensions and corresponding oximeter saturations obtained breathing air, 40% oxygen and 99.6% oxygen in normal persons. Their data and theoretical reasoning suggested that blood hæmoglobin was approximately 96-98% saturated at 100 mm. Hg oxygen tension with the subject breathing air. Following a period of 40% oxygen inhalation a mean increase in oximeter readings of 2.43% was found. It was calculated that this corresponded to an alveolar oxygen tension of 240 mm. Hg. If 100% oxygen was then administered, a further average increase of 0.89% was registered. The corresponding alveolar oxygen tension was about 657 mm. Hg. Small but definite and measurable oximetric changes in arterial saturation occur therefore with very large changes in oxygen tensions.

The findings of Fowler and Comroe[14] and Douglas and Edholm[15] suggest that oximetric oxygen saturation while breathing room air is about 96%. The breathing of 35-40% oxygen increases arterial oxygen tension by about another 100 mm. Hg. According to Douglas and Edholm 35% oxygen increases arterial oxygen saturation by about 3.5% to 99.5%. Any further increase in inhaled oxygen concentration results in a negligible change in oximetric saturation, a large increase in arterial oxygen tension and a relatively small increase in dissolved oxygen. It is interesting that 35% oxygen (arterial oxygen tension about 200 mm. Hg) appears, from clinical observation, to be the level above which retrolental fibroplasia is increasingly encountered in susceptible infants.

These considerations indicate that if an infant's blood can be shown to be 95-98% saturated oximetrically, the arterial oxygen tension is unlikely to be at dangerous levels. The relative accuracy of the oximetric saturation can be checked in an infant showing a normal saturation in air by

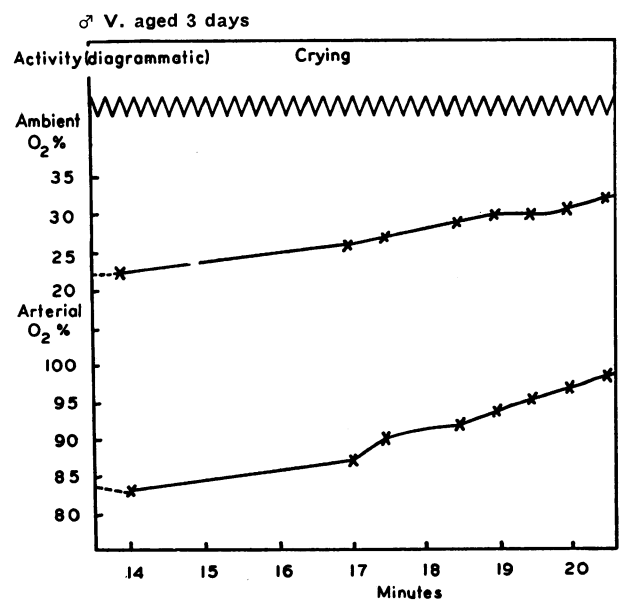

Fig. 4.—Birth weight 5 lb. ½ oz. Restoration of normal SaO_2 with 30% O_2.

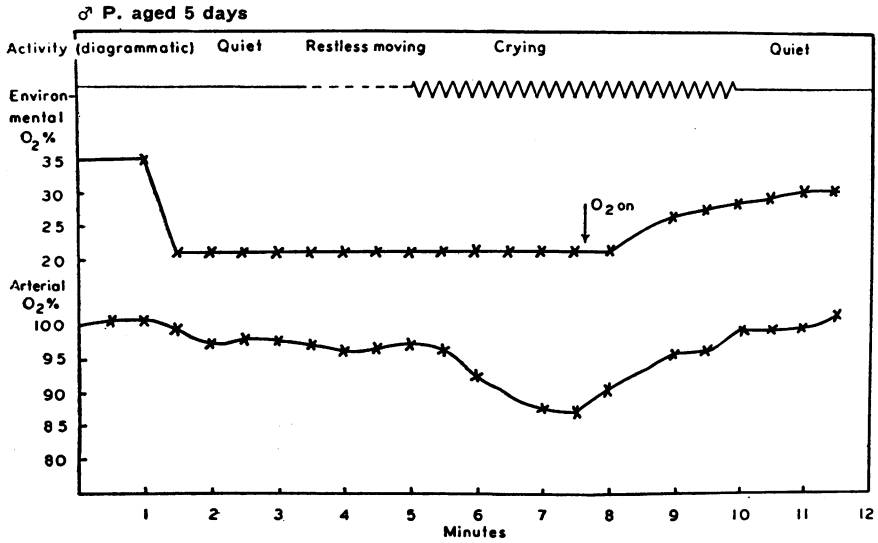

Fig. 5.—Birth weight 6 lb. 1 oz. This record shows a fall in SaO_2 on crying which is abolished by 30% supplemental oxygen.

giving 100% oxygen by mask to breathe for a short period. An increase in arterial oxygen saturation of the order of 3% would indicate normal saturation/tension relationships at the previous level.

It therefore follows that if inspired oxygen is limited to the minimum concentration which will produce approximately 96% arterial saturation measured by ear oximeter, the partial pressure of oxygen in arterial blood will remain close to the safe 100 mm. Hg level. Thus, by controlling inspired oxygen concentration and measuring at intervals arterial oxygen saturation the dangers of both hypoxia and hyperoxia will be avoided and a practical solution to the problem of control afforded (see Figs. 1 to 5).

It has been assumed in the foregoing discussion that there is no significant difference between the oxygen-hæmoglobin dissociation curves for fetal and adult bloods at oxygen tensions over 100 mm. Hg.

The number of cases in this series is too small for any firm conclusions to be drawn, but some insight has been gained into the sort of information to be obtained by oximetry in the newborn.

It is already well established[14] that the clinical assessment of hypoxia in adults is fallacious. Our observations have shown that about half of our infants receiving oxygen on clinical grounds did not in fact require it, if an arterial oxygen saturation of 96% in air is accepted as normal. It has however been the policy in this hospital to use oxygen in a concentration not exceeding 35% in cases showing dyspnœa and/or doubtful or episodic cyanosis, as an insurance against hypoxia. It has been felt that, provided the oxygen concentration is controlled strictly, there is little danger of retrolental fibroplasia even in small prematures. There has in fact been no known case of retrolental fibroplasia while this policy has been in force. With the advent of closer control by oximetry it may well be that oxygen can be dispensed with in these clinically borderline cases. Oxygen should continue to be available for the treatment of blue spells.

Of the remaining half in the series most required oxygen for five days or less.

There has been an increasing tendency to restrict oxygen to 35% without regard to individual requirements. The fact that one-third of our cases required more than 35% oxygen to achieve a normal saturation initially shows that this policy has its dangers. Serial daily observations on these cases indicated that, if recovery ensues, there is a progressive diminution in the percentage requirement for supplemental oxygen over four or five days (Fig. 7). Thus there is a case for the individual control of supplemental oxygen rather than the application of a blanket rule of percentage oxygen concentration. No concentration of oxygen, however high, is likely to result in retrolental fibroplasia to an infant weighing less than 1800 grams if central cyanosis (not peripheral cyanosis) persists while in that concentration. Persisting central cyanosis under these circumstances indicates that there is a block in the absorption of oxygen which cannot be surmounted by supplementing, or a central right to left blood shunt.

The demonstration of a central right to left shunt through a persisting ductus arteriosus in one case shows that arterial oxygen desaturation

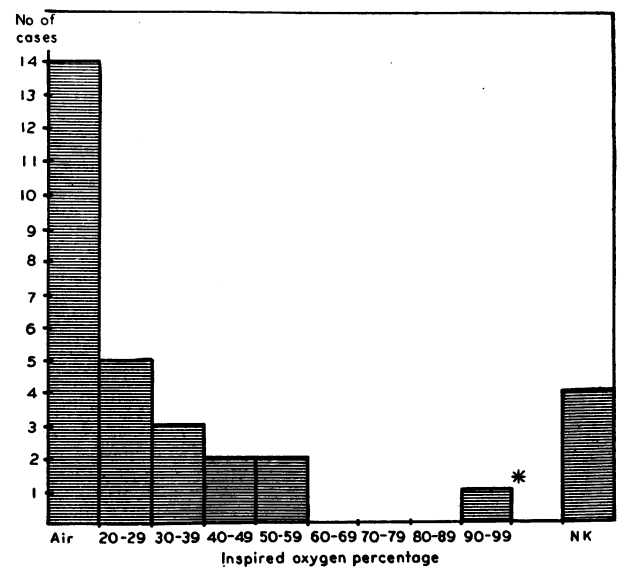

Fig. 6.—The distribution of 31 cases according to minimum inspired oxygen levels necessary for normal saturation. NK = Not known.
*Normal arterial saturation could not be obtained in this case even with pure oxygen.

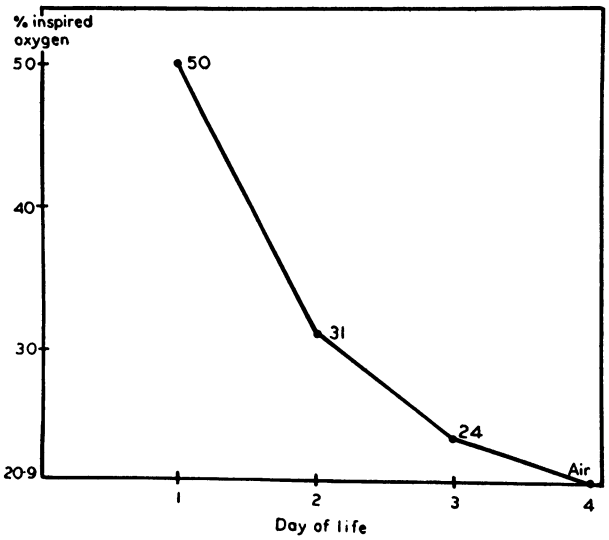

Fig. 7.—Case Br. This graph illustrates the daily reduction in minimum supplemental oxygen required for normal arterial oxygen saturation.

may not always be entirely respiratory in origin. Recent work[17] suggests that hypoxia may be accompanied by a raised pulmonary artery pressure in the newborn which would favour a right to left flow through fetal passages. There is therefore an intimate relation between pulmonary and hæmodynamic factors in the causation of arterial desaturation which requires further investigation.

Infants over 5 lb. (2270 grams) in birth weight are most unlikely to get retrolental fibroplasia under any conditions of partial pressure of arterial oxygen or ambient oxygen concentration. However, recent work[18–20] indicates that excessive oxygen may be a factor in the formation of hyaline membranes in the infant lung.

Our results indicate that oximetry can be used to control supplemental oxygen administration at the minimum level necessary to secure physiological oxygenation of arterial blood. Hyperoxia can be avoided in those weight groups susceptible to retrolental fibroplasia, and hypoxia due to ill-advised adherence to a rigid rule of thumb limitation of supplemental oxygen can also be eliminated.

It was noted incidentally that a normal arterial oxygen saturation could exist even in the presence of severe dyspnœa, and it was felt that dyspnœa alone was not a reliable indication for supplemental oxygen.

SUMMARY

This paper reports the results of an investigation into the use of the diamagnetic oxygen analyser and the Wood spectrophotometric ear oximeter in the assessment of arterial oxygen saturation in neonates and its relation to supplemental oxygen administration.

Almost half of the 31 infants probably received oxygen unnecessarily though not harmfully. Of those who required oxygen about one-third needed a percentage greater than 35 initially. The required level for normal arterial oxygen saturation dropped progressively over about five days to the atmospheric level (20.9%) in most cases.

Our thanks are due to the many members of the staff of the Hospital for Sick Children who kindly allowed us to investigate their patients, and to Mrs. B. Anderson for able technical assistance.

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RÉSUMÉ

Dans l'oxygénothérapie du nouveau-né, le pédiatre doit éviter le Charybde de l'hypoxie sans toutefois sombrer dans le Scylla de la fibroplasie rétrolentaire. Les auteurs de cet article ont cherché à vérifier les résultats produits par l'administration supplémentaire d'oxygène telle que dictée par les données cliniques. La saturation du sang artériel en oxygène fut déterminée chez 31 nourrissons en incubateur à l'aide de l'oxymètre photoélectrique de Wood apposé au lobe de l'oreille, et l'analyseur d'oxygène diamagnétique. Les résultats ont montré que sans détriment à leur santé, près de la moitié du groupe de ces enfants reçut de l'oxygène sans raison suffisante. Par contre, environ un tiers exigea une concentration supérieure aux 35% qui forment la limite généralement acceptée dans l'administration d'oxygène au nouveau-né. De ce dernier groupe, la plupart des nourrissons qui survécurent n'eut besoin d'une telle concentration que pendant une période très brève; le besoin d'oxygène étant satisfait par la concentration atmosphérique normale après quatre ou cinq jours.

La difficulté dans l'administration de l'oxygène ne réside pas dans le dépistage de son déficit dans le sang, mais au contraire, dans la direction opposée. La courbe de dissociation de l'oxygène se termine à son extrémité supérieure par un plateau, de sorte que les quelques variations en oxyhémoglobine enregistrées par l'oxymètre ne se produisent qu'à la suite de fortes variations de concentration dans la tension d'oxygène. En somme, si le sang d'un enfant montre une saturation de 95 à 98% à l'oxymètre, la tension du sang artériel en oxygène ne risque pas d'être dangereusement basse, et il n'est pas nécessaire d'augmenter la concentration d'oxygène qui permet déjà ce degré de saturation. Les auteurs recommandent donc un usage plus étendu de l'oxymétrie dans l'oxygénothérapie afin d'en régler l'administration de plus près.

PREGNANCY AFTER PNEUMONECTOMY

It would appear from a small series of patients studied by Williams (*Brit. M. J.*, 2: 1087, 1957) that once a woman who has undergone pneumonectomy for tuberculosis has reached the stage of "apparent cure", childbearing presents no undue hazard provided her respiratory capacity is reasonably good. The follow-up so far has given no indication that the responsibilities of looking after a limited family are dangerous to her future health. Consultation between the obstetrician and the chest physician is of the greatest importance.