

EFFECTS OF DIFFERENT OXYGEN CONCENTRATIONS DURING GENERAL ANAESTHESIA FOR ELECTIVE CAESAREAN SECTION*

GERTIE F. MARX, M.D., AND CYNTHIA V. MATEO, M.D.†

IN A PREVIOUS STUDY of mother and infant during caesarean section,¹ we reported that thiopentone-nitrous oxide-succinylcholine anaesthesia was associated with lower Apgar scores and longer "time to sustained respiration" of the neonate than spinal analgesia, despite comparable acid-base data. Quite unexpectedly, we noted also a very favourable clinical status of several newborn infants after emergency caesarean section for placenta praevia or abruptio placentae coincident with the use of light cyclopropane anaesthesia and postulated this to be related to the high inspired oxygen concentration. Recent studies by Newman *et al.*² and by Althabe and his coworkers³ demonstrated a rise in oxygen tensions of foetal scalp capillary blood and foetal tissues when pregnant women breathed increased oxygen concentrations. Quilligan and his associates⁴ showed an elevation in oxygen tension of intervillous space blood and umbilical vein blood in four patients undergoing caesarean section under spinal analgesia during the maternal inhalation of oxygen for five minutes. And Fox and Houle,⁵ in comparing epidural-air and epidural-oxygen analgesia during caesarean section, found that infants in the latter group had higher oxygen tensions, a lower degree of metabolic acidosis, and a more rapid onset of spontaneous respiration. We, therefore, decided to investigate the effects on foetus and neonate of different oxygen concentrations during general anaesthesia for elective repeat caesarean section.

METHOD

Seventy-five healthy term-pregnant women were divided into five sequential groups. Except for the anaesthetic agent and the concentration of inhaled oxygen used for maintenance of anaesthesia, they were managed identically. Left uterine displacement was instituted prophylactically, a continuous infusion of lactated Ringer's solution with 5 per cent dextrose was administered and atropine 0.4 mg injected intravenously. During preoxygenation, the patient's minute volume was measured with a Wright Respirometer incorporated into the circle system. Induction of anaesthesia with 200–250 mg of thiopentone (Pentothal) was followed by injection of 60 mg of succinylcholine (Anectine) and endotracheal intubation. A succinylcholine solution, 0.1 per cent, was infused during maintenance, and respirations were controlled manually with the preanaesthetic minute volume as a guide.

*Presented in part at the American Society of Anesthesiologists' Meeting, New York City, October 1970.

†From the Department of Anesthesiology of the Albert Einstein College of Medicine and Affiliated Hospitals, Bronx, New York, U.S.A.

Based on known values of relative MAC (minimum alveolar concentration) in normal man,^{6,7} the delivered concentrations of the different anaesthetic agents were calculated to produce comparable levels of light anaesthesia (approximately 2/3 MAC).

Twenty-five patients received what we designated as a low oxygen concentration; 13 of these were given 28 per cent oxygen-6½ per cent cyclopropane (400-425 ml of C₃H₆ added to 6 liters of a mixture of 70 per cent nitrogen-30 per cent oxygen) (third group) and 12 were anaesthetized with 33 per cent oxygen-67 per cent nitrous oxide (2 L : 4 L) (first group). Twenty-five women received a medium oxygen concentration consisting of 66 per cent oxygen-33 per cent nitrous oxide (4 L : 2 L)-1¼ per cent fluroxene (Fluoromar) (fifth group). And 25 patients were given a high oxygen concentration; 12 of these received 93 per cent oxygen-6½ per cent cyclopropane (400-425 ml of C₃H₆ added to 6 liters of oxygen) (second group) and 13 received 97 per cent oxygen-2½ per cent fluroxene (O₂ 6 liters) (fourth group).

At the time of delivery, blood samples were obtained from the maternal radial artery as well as from the umbilical vein and artery of a cord segment doubly clamped prior to the infant's first breath. A sample of the inspired anaesthetic mixture was also checked for oxygen concentration. The oxygen, carbon dioxide and pH determinations were made with Radiometer electrodes and read-out system. Base change was calculated from the nomogram of Siggaard-Andersen *et al.*,⁸ and the foetal oxygen saturation from the dissociation curve of Nelson *et al.*⁹ The clinical condition of the newborn infants was evaluated according to the recommendations of Apgar¹⁰ and James *et al.*¹¹

The data are expressed as the mean \pm 1 standard error. Student's *t*-test and the coefficient of correlation¹² were used for the statistical analyses.

RESULTS

Maternal arterial carbon dioxide tensions were within \pm 3 torr of normal (30-34 torr) in all patients, eliminating the potential effects of hyper- or hypoventilation on the foetus. Maternal blood pH and base change values were also within close ranges (Table I). Likewise, umbilical vein and artery blood pH and carbon dioxide

TABLE I
MATERNAL ARTERIAL CARBON DIOXIDE TENSIONS, pH AND BASE CHANGE VALUES WERE WITHIN CLOSE RANGES IN ALL GROUPS

Anaesthetic	No. cases	PaCO ₂ (torr)	pH	Base deficit (mEq/l)
Low O ₂ concentration	25	31.6 \pm 0.9	7.42 \pm 0.01	3.8 \pm 0.4
28% O ₂ -6½% C ₃ H ₆	13	32.4 \pm 1.0	7.41 \pm 0.01	3.8 \pm 0.6
33% O ₂ -67% N ₂ O	12	30.8 \pm 0.8	7.42 \pm 0.02	3.8 \pm 0.6
Medium O ₂ concentration	25	30.2 \pm 0.6	7.42 \pm 0.01	3.6 \pm 0.3
65% O ₂ -33% N ₂ O-1¼% C ₄ H ₈ OF ₂	25	30.2 \pm 0.6	7.42 \pm 0.01	3.6 \pm 0.3
High O ₂ concentration	25	32.8 \pm 0.8	7.41 \pm 0.01	3.3 \pm 0.6
93% O ₂ -6½% C ₃ H ₆	12	32.3 \pm 0.9	7.42 \pm 0.01	3.0 \pm 0.9
97% O ₂ -2½% C ₄ H ₈ OF ₂	13	33.2 \pm 0.8	7.41 \pm 0.02	3.6 \pm 0.6

TABLE II

UMBILICAL VEIN (UV) AND ARTERY (UA) BLOOD CARBON DIOXIDE TENSIONS AND pH VALUES DID NOT DIFFER MARKEDLY IN THE VARIOUS GROUPS

Anaesthetic	P(uv) CO ₂ (torr)	uv pH	P(ua) CO ₂ (torr)	UA pH
Low O ₂ concentration	39.2±1.2	7.33±0.01	46.8±1.3	7.26±0.01
28% O ₂ -6½% C ₃ H ₆	39.0±1.3	7.34±0.02	45.8±1.6	7.27±0.02
33% O ₂ -67% N ₂ O	39.4±2.1	7.32±0.02	47.9±2.2	7.26±0.02
Medium O ₂ concentration				
65% O ₂ -33% N ₂ O-1¼% C ₄ H ₅ OF ₃	39.0±1.0	7.33±0.02	46.2±1.2	7.27±0.01
High O ₂ concentration				
93% O ₂ -6½% C ₃ H ₆	40.1±1.4	7.34±0.01	47.2±1.8	7.27±0.01
97% O ₂ -2¼% C ₄ H ₅ OF ₃	38.8±2.6	7.36±0.02	44.0±3.4	7.30±0.02
	41.2±1.6	7.32±0.02	49.8±1.5	7.26±0.01

TABLE III

MATERNAL, UMBILICAL VEIN AND UMBILICAL ARTERY BLOOD OXYGEN TENSIONS WITH DIFFERENT INSPIRED OXYGEN TENSIONS

Anaesthetic	Measured inspired PO ₂ (torr)	PaO ₂ (torr)	P(uv)O ₂ (torr)	P(ua)O ₂ (torr)
Low O ₂ concentration	230±4	107.20±5.21	29.72±1.50	18.56±1.46
28% O ₂ -6½% C ₃ H ₆	209±2	90.77±2.72	31.00±6.36	19.08±1.80
33% O ₂ -67% N ₂ O	252±2	125.00±7.70	28.33±2.42	18.00±2.40
Medium O ₂ concentration				
65% O ₂ -33% N ₂ O-1¼% C ₄ H ₅ OF ₃	488±2	282.60±9.97	34.96±1.05	23.04±0.72
High O ₂ concentration				
93% O ₂ -6½% C ₃ H ₆	718±4	387.32±12.29	41.20±1.59	25.96±1.11
97% O ₂ -2¼% C ₄ H ₅ OF ₃	698±2	381.42±14.82	40.17±2.22	26.75±1.10
	736±1	392.77±19.76	42.15±8.40	25.23±1.30

NOTE: The differences between low-, medium-, and high-oxygen groups are statistically significant ($p < 0.001$ for maternal values, $p < 0.01$ or < 0.05 for foetal values).

values did not differ markedly in the various groups (Table II). On the other hand, oxygen tensions in both maternal and foetal bloods were significantly different; they were lowest in the two groups receiving low inspired oxygen, intermediate in the group inhaling the 2/3 oxygen mixture, and highest in the two groups anaesthetized with high inspired oxygen (Table III). The correlation coefficient between maternal and umbilical vein blood oxygen tension was 0.60 ($p < 0.01$) in the 25 cases of the low-oxygen groups, 0.44 ($p < 0.05$) in the 25 cases of the medium oxygen group, and 0.30 (not significant) in the 25 cases of the high oxygen groups. The corresponding correlation coefficients between umbilical vein and artery blood oxygen tensions were 0.83 ($p < 0.001$), 0.59 ($p < 0.01$) and 0.43 ($p < 0.05$). Oxygen saturation and oxygen content of the cord bloods were also significantly different among the high, medium, and low inspired oxygen groups (Table IV).

Although the induction-delivery intervals were similar, the clinical condition of the neonates differed. Mean time to sustained respiration was 57 seconds in the low oxygen groups, 19 seconds in the medium oxygen group and 12 seconds in the high oxygen groups ($p < 0.001$ between low and medium or high). Twelve infants in the low oxygen groups scored 7 or less on the one-minute Apgar score as compared to four infants in the medium and two in the high oxygen groups (Table V).

TABLE IV
UMBILICAL VEIN AND ARTERY BLOOD OXYGEN SATURATION AND CONTENT

Inspired oxygen concentration	O ₂ saturation (%)		O ₂ content (ml)	
	UV	UA	UV	UA
Low	58.3±3.8	30.4±3.1	12.5±0.8	6.6±0.7
Medium	68.8±1.7	38.5±1.8	14.8±0.4	8.3±0.4
High	77.0±2.0	46.7±2.1	16.3±0.4	9.9±0.5

NOTE: The differences between the groups were statistically significant ($p < 0.001$ between low and high oxygen concentration groups, $p < 0.01$ or < 0.05 between (a) low and medium and (b) medium and high groups).

TABLE V
THE CLINICAL CONDITION OF THE NEWBORN INFANTS IMPROVED WITH INCREASING INSPIRED OXYGEN CONCENTRATION

Inspired oxygen concentration	I.D.T. (min)	T.S.R. (sec)	No. infants scoring 7-or-less
Low	12.4±1.0	57.3±7.9	12
Medium	12.5±0.7	18.8±3.2	4
High	13.0±0.7	12.2±3.1	2

NOTE: The differences in time to sustained respiration are statistically significant between low- as compared to medium- and high-oxygen groups ($p < 0.001$).

TABLE VI
FOETAL AND NEONATAL RESULTS IMPROVED WITH INCREASING MATERNAL ARTERIAL OXYGEN TENSION

Maternal PaO ₂ (torr)	61-100	101-160	181-240	241-300	301-360	361-420	421-520
No. cases	13	12	3	10	19	11	7
P(uv)O ₂ (torr)	28.6 (±1.9)	30.9 (±2.3)	29.0	35.1 (±0.4)	38.3 (±1.7)	40.5 (±2.7)	41.3 (±2.6)
P(ua)O ₂ (torr)	16.1 (±1.9)	20.3 (±2.1)	20.7	22.5 (±1.0)	25.1 (±1.0)	26.1 (±1.5)	25.1 (±1.0)
T.S.R. (sec.)	61.5 (±7.8)	54.2 (±14.4)	33.3	26.7 (±6.7)	11.1 (±3.2)	12.5 (±4.6)	14.3 (±3.7)
No. infants with score "7-or-below"	7	5	2	2	1	1	0
"6-or-below"	4	2	1	0	0	0	0

NOTE: There was no further change as the material oxygen tension rose above 300 torr.

Analysis of the foetal and neonatal data revealed the lowest foetal oxygenations and longest times to sustained respiration when the maternal PaO₂ was below 100 torr and the highest foetal oxygenations and shortest times to sustained respiration when the PaO₂ was 300 torr or more. However, there was no further foetal or neonatal change as the maternal oxygen tension rose above 300 torr (Table VI).

DISCUSSION

The results of the study show that the clinical condition of the infant was improved when umbilical cord blood oxygenation had been increased by elevation

of the maternal arterial oxygen tension. Although three anaesthetic agents were employed and differences in their effect on the foetus cannot be excluded, the similarity of results in the two low as well as the two high-oxygen groups and the difference in results between the two cyclopropane groups point to the inspired oxygen concentration as a critical factor. Optimal conditions were obtained when the maternal P_{aO_2} was 300 torr or higher. This finding is in agreement with similar recent studies. Baraka,¹³ in 15 elective caesarean sections managed under general anaesthesia with different oxygen concentrations, observed that foetal oxygen tension was positively correlated with maternal oxygen tension in the range of 78 to 200–300 torr, but was not further increased with elevation of the maternal oxygen tension to 500 torr. Rorke, Davey and Du Toit,¹⁴ in a series of 34 elective caesarean sections performed with inhalation anaesthesia, demonstrated a significant correlation between the level of foetal oxygenation and the clinical state of the infant at birth as assessed by the Apgar score. Fourteen of their patients received 65 per cent nitrous oxide-33 per cent oxygen-2 per cent ether, ten women were given 33 per cent nitrous oxide-65 per cent oxygen-2 per cent ether, and the remaining ten received oxygen with 0.3 per cent methoxyflurane (Penthane). With increase in maternal P_{aO_2} to approximately 300 torr (eight of the women receiving 65 per cent oxygen), a significant ($p < 0.001$) increase in umbilical vein and artery blood oxygen tensions occurred, but with elevation above 300 torr (women receiving over 99 per cent oxygen), there was a progressive (although statistically not significant) decrease in the foetal oxygen levels. However, a small but significant ($p < 0.01$) increase in maternal arterial carbon dioxide tension was noted with the increase in oxygen tension and was associated with an even greater increase in foetal carbon dioxide levels. These differences in carbon dioxide levels may have been responsible for the slight decrease in foetal oxygenation since a similar decrease was not observed by Newman² or by us, although the mechanism is difficult to explain.

Because of the greater acidity of foetal blood and the slope of the foetal oxygen-dissociation curve, an increase in foetal oxygen leads to a relatively greater increase in oxygen saturation and content. The greater oxygen content compensates for the decrease in total blood volume or red cell volume associated with abdominal delivery which may result from failure to receive placental blood or from actual loss of blood into the placenta.¹⁵ An increased oxygen content may also act as a reservoir permitting the neonate to withstand postnatal apnoea or postnatal deprivation of oxygen during suctioning of the airway for longer periods. In a neutral thermal environment, the oxygen-consumption of the human newborn infant is approximately 4.6 ml/kg/min.¹⁶ A three-kilogram infant from our high-oxygen group (umbilical artery oxygen content 9.9 ml) would, thus, have a 43-second supply of oxygen at birth as compared to a 29-second reserve in a similar infant from the low-oxygen group (umbilical artery oxygen content 6.6 ml), an increase of 50 per cent.

Since the shunts across the maternal pulmonary circulation and across the placenta^{14,17} are large yet unpredictable, and since we found no deterioration in the foetal or neonatal well-being with increases in maternal oxygen tension, we believe that an inspired oxygen concentration of close to 100 per cent is optimal for caesarean section provided that pain and awareness by the parturient woman¹⁸ can be avoided. Considering the effects on both the mother and the infant, our best results were obtained with cyclopropane-oxygen. When this agent cannot be used,

a 33 per cent nitrous oxide-67 per cent oxygen-mixture potentiated by a halogenated vapour seems to be a rational substitute.

SUMMARY AND CONCLUSIONS

The influence of different oxygen concentrations on foetal oxygenation and neonatal clinical status during general anaesthesia for elective caesarean section was evaluated in 75 term-pregnant women. One-third of the patients received what we designated as a low oxygen concentration (28 per cent or 33 per cent), one-third a medium concentration (65 per cent), and one-third a high concentration (93 per cent or 97 per cent).

Oxygen tensions in both maternal and foetal bloods as well as oxygen saturation and content of foetal bloods increased significantly with increases in the inspired oxygen concentration. Foetal oxygenation was lowest and time to sustained respiration longest when maternal PaO_2 was below 100 torr. Foetal oxygenation was highest and time to sustained respiration shortest when maternal PaO_2 was 300 torr or more; no further foetal or neonatal change occurred as the maternal oxygen tension rose above 300 torr.

An inspired oxygen concentration of at least 65 per cent is recommended for caesarean section anaesthesia.

RÉSUMÉ

L'influence de différentes concentrations d'oxygène sur le fœtus et le nouveau né pendant l'anesthésie générale pour césariennes sélectives a été évaluée chez 75 grossesses à terme. Un tiers des patients a reçu ce que nous avons désigné comme concentration basse d'oxygène (28 pour cent ou 33 pour cent); un tiers a reçu une concentration moyenne (65 pour cent) et le dernier tiers une concentration forte (93 pour cent ou 97 pour cent).

Les tensions et saturations sanguines d'oxygène chez la mère et chez le fœtus ont augmenté proportionnellement avec la fraction inspirée d'oxygène. L'oxygénation fœtale fut la plus basse et le temps de respiration soutenue le plus élevé quand la tension maternelle d'oxygène fut au dessous de 100 torr. L'oxygénation fœtale fut maximale et le temps de respiration soutenue le plus court quand la tension maternelle d'oxygène fut à ou dessus de 300 torr. Aucun changement fœtal ou néonatal n'a été observé quand la tension d'oxygène maternelle fut au dessus de 300 torr.

Une concentration d'oxygène inspiré d'au moins 65 pour cent est recommandée pour l'anesthésie de la césarienne.

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