RIGHT ATRIAL OXYGEN LEVELS DURING ANAESTHESIA AND SURGERY*

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PREVIOUS STUDIES during whole-body perfusion,¹ hypothermia,² induced hypotension,³ and other surgical procedures⁴ suggested that knowledge of right atrial oxygen saturation might be useful clinically in evaluating the oxygen-transport system of anaesthetized patients. In these studies measured right atrial oxygen saturations were similar to predicted mixed venous (pulmonary artery) oxygen saturations, and this reflected the interrelationship of arterial oxygen content, oxygen uptake, and cardiac output.⁴ In order to evaluate the clinical practicality and usefulness of monitoring right atrial oxygen saturations, 38 patients undergoing a variety of neurosurgical procedures were studied.

METHODS AND MATERIALS

Adult patients were studied during prolonged neurosurgical procedures and in a variety of positions. Premedicants were atropine (0.4 mg.) and either hydroxyzine (50 mg.) or meperidine (50 to 75 mg.). After induction with thiopental (150 to 500 mg.) and endotracheal intubation with the aid of succinylcholine (80 mg.), anaesthesia was maintained with halothane (0.5 to 1.0%) in either nitrous oxide (60%) and oxygen or 100 per cent oxygen using a circle-absorption system. Ventilation was controlled with a Bird ventilator (Mark IV) set to deliver a tidal volume of 600 to 900 ml. at a frequency of 10 to 12 per minute. Succinylcholine (100 to 400 mg.) was administered intermittently as required for surgical relaxation.

In six patients, catheters prepared by the method of Fife and Lee⁵ were used in an attempt to catheterize the main pulmonary artery. This approach was abandoned, however, due to the occurrence of ventricular tachycardia in five of the patients when the catheter entered the right ventricle. In 32 patients a catheter (PX 039, 536; Becton-Dickinson, Rutherford, N.J.) was placed in the right atrium according to the technique of Robertson and associates.⁶ The catheter was filled with normal saline solution, connected to the V lead of a standard ECG machine, and advanced through a medical antecubital vein until the characteristic biphasic P-wave appeared. In ten patients, the catheter was placed prior to induction of anaesthesia and samples were obtained while the patient was awake. In all patients, right atrial samples were obtained at intervals of 15

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to 30 minutes throughout the surgical procedure and anaesthesia. Percentage saturation of haemoglobin with oxygen (O_2 saturation) was determined by reflection oximetry (American Optical Model 10800).⁷ Oximeter readings were corrected by means of a calibration curve based on Van Slyke determinations.

Additional measurements included arterial pressure, heart rate, central venous pressure (strain gauge), oesophageal temperature (thermistor), concentration of inspired oxygen (Beckman O_2 Analyzer), and concentration of haemoglobin (cyanmethaemoglobin). Arterial samples were obtained on occasion for determination of O_2 saturation, pH, PCO_2 , and PO_2 (electrodes, $37^\circ C$).

RESULTS

No complications were associated with the placement of the right atrial catheter in the 32 patients. Preoperative right atrial oxygen saturation in ten patients breathing room air averaged 72 per cent (Table I). This finding compares to a mean value of 71 per cent obtained 15 to 30 minutes after induction of anaesthesia and prior to surgical stimulation. Greater variance was present in samples taken at random during the induction period.

TABLE I
COMPARISON OF RIGHT ATRIAL OXYGEN SATURATIONS (%) IN
AWAKE AND ANAESTHETIZED PATIENTS

Patient	Awake	Anaesthetized	
		induction	15-30 minutes after induction
7	63	54	72
9	64	66	66
15	77	85	75
18	59	47	62
20	81	84	77
26	67	56	72
31	78	75	71
32	75	85	71
33	80	72	77
34	72	69	69
Mean	72	69	71
Standard deviation	8	14	5
Standard error	2	4	1

In five patients no significant alterations in cardiopulmonary function were recognized during operation, and in these patients right atrial oxygen saturation was normal and varied little (Table II).

In the remaining 27 patients, clinical signs of altered pulmonary or circulatory function were present at some time during the procedure and were reflected by changes in right atrial oxygen saturation. These alterations were secondary to the administration of urea (13 patients), induced hypotension with trimethaphan (3 patients), haemorrhage requiring transfusion of 1000 ml. or more of blood (9 patients), air embolism (1 patient), or endobronchial intubation (1 patient). Variation in the patient's position (sitting, prone, and supine) did not appear in itself to affect right atrial oxygen saturations. Six cases have been selected for illustrative purposes (Figs. 1 through 6).

TABLE II
SERIAL RIGHT ATRIAL OXYGEN SATURATIONS (%) DURING
ANAESTHESIA AND IN ABSENCE OF CARDIOPULMONARY
ABNORMALITIES

Patient	Initial sample	During anaesthesia		
		after 1 hr.	after 2 hrs.	after 3 hrs.
10	62	66	66	66
22	67	64	64	68
25	75	82	78	77
35	71	68	66	69
36	61	60	61	66

FIGURE 1. Effect of urea administered rapidly. Administration of 60 gm. of urea in 15 minutes produced transient hypervolaemia resulting in abrupt increase in arterial and central venous pressures, heart rate, and right atrial oxygen saturation. With diuresis, all measured variables decreased. Initial rise in right atrial oxygen saturation in presence of decrease in haemoglobin suggests that increase in cardiac output more than compensated for reduced oxygen capacity of blood.

FIGURE 2. Effect of urea administered slowly. After administration of 60 gm. of urea in 55 minutes, only modest changes occurred in arterial and central venous pressure, heart rate, and right atrial oxygen saturation. During this period changes in right atrial oxygen saturation apparently reflected changes in haemoglobin.

Figures 1 and 2 contrast the haemodynamic effects of urea administered at different rates and are consistent with expected effects of changes in cardiac output and haemoglobin on right atrial oxygen saturation. Figure 3 illustrates the effects of a period of induced hypotension. The absence of a significant decrease in right atrial oxygen saturation suggests that cardiac output was well maintained despite the lowered arterial pressure. Figure 4 illustrates the response of right atrial oxygen saturation to haemorrhage and transfusion. In this situation, change in right atrial oxygen saturation apparently reflects changes in both haemoglobin and cardiac output. In Figure 5, an episode of air embolism that was not accompanied by major changes in arterial pressure or pulse rate was reflected by only a modest change in central venous pressure but by a considerable decrease in right atrial oxygen saturation. Figure 6 illustrates the effect of a significant decrease in arterial oxygen on right atrial oxygen saturation. In this patient a remarkable decrease in oxygen saturation was not associated with meaningful alterations in arterial pressure, central venous pressure, or heart rate.

FIGURE 3. Effect of induced hypotension (trimethaphan, 100 mg.). Reduction of mean arterial pressure to 55 mm. Hg for 30 minutes was accompanied by modest increase in heart rate and insignificant decrease in right atrial oxygen saturation. Despite significant decrease in arterial pressure, no major change in cardiac output is apparent.

COMMENT

Knowledge of right atrial oxygen saturation permits certain deductions to be made about the oxygen transport system. These deductions are clarified by examining the following rearranged Fick equation:

$$\text{mixed venous oxygen content} = \text{arterial oxygen content} - \frac{\text{oxygen uptake}}{\text{cardiac output}}.$$

From this equation it is apparent that mixed venous oxygen content is the result of the interrelationship of arterial oxygen content, oxygen uptake, and cardiac output. If this value is within normal limits, no profound disparity exists between arterial oxygen content and the relationship of cardiac output to oxygen consumption.⁴ If it is abnormally low, a disparity exists in the oxygen system which can be elucidated only in conjunction with other laboratory or clinical observations. During anaesthesia under normothermic conditions, changes in oxygen

FIGURE 4. Effect of haemorrhage and transfusion. Progressive decrease in right atrial oxygen saturation in the second hour was likely the resultant of decrease in both haemoglobin and cardiac output. Only moderate changes occurred in arterial and venous pressures. When blood loss was replaced, right atrial oxygen saturation along with arterial and venous pressures returned toward normal levels. Low preoperative concentration of haemoglobin in this patient and unsteady haemodynamics following induction were associated with initial low right atrial oxygen saturation.

uptake can generally be disregarded as a possible cause of variation in mixed venous oxygen levels,^{8,9} and any change which does occur must reflect a change either in arterial oxygen content or in cardiac output or in both.

Ideally, venous samples should be obtained from the main pulmonary artery. However, our experience in six patients indicated that catheterization of the pulmonary artery was both impractical and hazardous for the purpose of clinical monitoring. In contrast, right atrial catheters were placed with little difficulty and no apparent hazard. Furthermore, previous studies had shown good agreement between measured right atrial oxygen levels and mixed venous oxygen

FIGURE 5. Effect of air embolism. Entrance of air into the heart resulted in decrease in right atrial oxygen saturation and modest increase in venous pressure, while arterial pressure and heart rate were little changed. These changes suggest reduction in cardiac output not reflected in arterial pressure or heart rate.

levels calculated from measured cardiac output and oxygen uptake.⁴ Localization of the right atrial catheter is greatly facilitated by electrocardiographic monitoring. The major problem associated with this technique is electric interference (60 cycle). This can be based on inadequate equipment, air bubbles, kinking of the catheter, obstruction of the catheter by a blood clot, presence of other electric devices, or inadvertent contact of a conducting surface with the patient. Catheterization of the coronary sinus rarely occurs but should be suspected when extremely low oxygen saturations are encountered; it can be corrected by slight withdrawal of the catheter.

In the 32 patients studied, useful clinical information was derived from knowledge of right atrial oxygen saturation. In the five patients in whom no alterations in circulatory or pulmonary function were recognized (Table II), right atrial oxygen saturation remained within normal range and was similar to awake values. In the remaining patients significant changes in right atrial oxygen

FIGURE 6. Effect of large shunt secondary to endobronchial intubation. With right endobronchial intubation and production of intrapulmonary shunting, parallel decreases occurred in arterial and right atrial oxygen saturations. Decreases were not accompanied by significant changes in arterial or central venous pressure or in heart rate. Removal of tube to trachea and hyperinflation resulted in return of both O₂ saturation values toward normal values.

saturation did occur and could be accounted for by alterations in cardiac output and arterial oxygen content. These changes were not always accompanied by corresponding changes in the variables usually monitored (Fig. 6). Similarly, significant changes in arterial pressure and heart rate were not always associated with corresponding changes in right atrial oxygen saturations (Fig. 3). Thus, the monitoring of right atrial oxygen saturation provides additional useful information in the clinical assessment of the anaesthetized patient. It should not, however, be

considered a replacement for the continuous and careful monitoring of arterial pressure, heart rate, and central venous pressure.

SUMMARY

Right atrial oxygen saturation was measured in 32 patients undergoing a variety of neurosurgical procedures. Initial efforts to sample mixed venous blood from the pulmonary artery resulted in a high incidence of ventricular tachycardia. For this reason, catheters were inserted only as far as the right atrium and were positioned by electrocardiographic means. Catheterization was easily accomplished and required a minimum of time and technical experience.

In the presence of normal haemodynamics and pulmonary function, right atrial oxygen saturations were steady and within normal limits. Changes in cardiac output secondary to haemorrhage, transfusion, urea infusion, and air embolus were reflected by early changes in right atrial oxygen saturations with or without concomitant changes in arterial pressure, venous pressure, and heart rate. Changes in arterial oxygen content secondary to shunting or decreased haemoglobin concentration were reflected in the right atrial oxygen saturations with or without concomitant changes in the other monitored variables. The monitoring of right atrial oxygen saturations provides useful additional information which contributes to proper evaluation and management of the anaesthetized patient.

RÉSUMÉ

Chez 32 malades subissant une variété d'opérations en chirurgie nerveuse, nous avons recherché le pourcentage de saturation en oxygène du sang dans l'oreillette droite. Au début, nous avons essayé d'obtenir un mélange de sang dans l'artère pulmonaire mais cette technique a provoqué, chez un fort pourcentage des malades, une tachycardie. C'est à cause de cela que nous nous sommes contentés d'introduire les cathéters jusque dans l'oreillette droite et nous avons précisé leur position par des moyens électrocardiographiques. Le cathétérisme s'est fait sans difficulté, dans un minimum de temps et sans exiger d'expérience technique.

Lorsque l'hémodynamique et la fonction pulmonaire demeuraient dans les limites de la normale, les saturations sanguines dans l'oreillette droite demeuraient stables et voisines de la normale. Si l'on modifiait le débit cardiaque soit par une hémorragie, une transfusion, l'injection d'urée, une embolie gazeuse, nous constatons aussitôt des changements dans les saturations d'oxygène, accompagnés ou non de variations de la tension artérielle et veineuse et de la fréquence cardiaque. Les changements de la tension d'oxygène artérielle dus à une dérivation artério-veineuse ou à une diminution du taux d'hémoglobine se percevaient sur les saturations en oxygène dans l'oreillette droite qu'il existe ou non des changements concomitants des autres variantes enregistrées. L'enregistrement des saturations en oxygène du sang dans l'oreillette droite procure des renseignements additionnels précieux; cela devient un facteur de plus dans l'évaluation adéquate du malade et la conduite de l'anesthésie.

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