Effect of positive end-expiratory pressure on intrapulmonary shunt at different levels of fractional inspired oxygen

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ABSTRACT In 10 patients undergoing ventilation, venous admixture was measured at different values of positive end-expiratory pressure (PEEP). The measurements were performed at the level of fractional inspired oxygen (F_{IO_2}) at which each patient was ventilated, and at $F_{IO_2}=1$. In patients ventilated at F_{IO_2} between 0·21 and 0·3 venous admixture was not modified by PEEP, while in patients ventilated with F_{IO_2} between 0·4 and 0·6, venous admixture decreased significantly ($p < 0·01$). With $F_{IO_2}=1$, increased PEEP produced a reduction in venous admixture in all cases ($p < 0·05$). These observations suggest that in patients similar to ours, PEEP does not reduce venous admixture at low levels of F_{IO_2} (0·21–0·3), and the observed reduction with PEEP at $F_{IO_2}=1$ may be misinterpreted.

In patients with acute respiratory failure, positive end-expiratory pressure (PEEP) has been said to reduce pulmonary venous admixture and improve arterial blood oxygenation.[1-3] The efficiency of PEEP can thus be evaluated by its influence on venous admixture. Most studies dealing with venous admixture are performed at $F_{IO_2}=1$. However, modifications of F_{IO_2} are known to alter shunt values.[4] It is not clear whether the beneficial effect of PEEP on pulmonary shunting at lower values of F_{IO_2} is the same as at $F_{IO_2}=1$. In this report we describe the results of investigations carried out on patients submitted to various levels of PEEP at different values of F_{IO_2}.

Patients and methods

The study was conducted on 10 adult patients ventilated with a Bennett MA-1 respirator for various reasons (table 1). Venous admixture was calculated without PEEP, and again at 5, 10, and 15 cm H_2O PEEP, after a 15-minute period of equilibrium at each PEEP level. For each patient measurements were performed at the F_{IO_2} as determined by the clinical status, and repeated at $F_{IO_2}=1$. The patients were sedated,

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and vital signs and minute volume were repeatedly checked, in order to confirm steady state conditions. Blood samples were drawn simultaneously into heparinised glass syringes from an indwelling arterial line and from a pulmonary artery catheter (Edwards Model 7FD). The venous admixture was calculated from the shunt equation:

$$\frac{\dot{Q}sp}{\dot{Q}t} = \frac{C\dot{c}o_2 - Cao_2}{C\dot{c}o_2 - C\bar{v}o_2}$$

Where: $Cao_2 = 1·39 \cdot Hb \cdot Sat_ao_2 + 0·0031 Pao_2$

$Cvo_2 = 1·39 \cdot Hb \cdot Sat_vo_2 + 0·0031 Pvo_2$

For $C\dot{c}o_2$ the alveolar air equation was used:

$PAo_2 = F_{IO_2} (P_{Bar} - P_{H_2O})$
$\qquad - Paco_2 (F_{IO_2} + (1 - F_{IO_2})/RQ)$

and the respiratory quotient (RQ) was calculated for patients ventilated with F_{IO_2} between 0·21 and 0·3 according to:

$$RQ = \frac{Feco_2 (1 - F_{IO_2})}{F_{IO_2} (1 - Feo_2 - Feco_2) - Feo_2} \qquad [5\,6]$$

For respiratory gases oxygen concentrations were measured using a paramagnetic oxygen analyser (Servomex OA-250) and carbon dioxide concentrations were determined with the Godart Capnograph. Blood gases and pH were measured with the Astrup Radiometer apparatus. Oxygen saturation was calculated according to the Gomez formula.[7] All calculations, including

Table 1 *Effect of PEEP on venous admixture at indicated F_{IO_2} and at $F_{IO_2} = 1$*

Diagnostic	Sex	Age (yr)	F_{IO_2}	PEEP (cm H_2O)				F_{IO_2}	PEEP (cm H_2O)			
				0	5	10	15		0	5	10	15
Multiple trauma, sepsis	M	46	0·21	0·26	0·28	0·25	0·26	1	0·25	0·24	0·23	0·21
Multiple trauma, uraemia	F	64	0·21	0·33	0·33	0·37	0·39	1	0·30	0·32	0·30	0·34
Chronic obstructive airways disease, sepsis	F	74	0·21	0·18	0·20	0·15	0·17	1	0·19	0·13	0·15	0·15
Brain contusion, pneumonia	M	32	0·29	0·28	0·36	0·31	0·39	1	0·20	0·17	0·20	0·22
Burns 85%	F	40	0·30	0·36	0·34	0·32	0·31	1	0·27	0·24	0·17	0·19
Chest trauma	F	32	0·40	0·17	0·20	0·12	0·10	1	0·24	0·24	0·26	0·24
Brain and lung contusion	M	64	0·40	0·32	0·27	0·35	0·29	1	0·30	0·28	0·25	0·18
Peritonitis, sepsis	M	78	0·41	0·34	0·29	0·29	0·32	1	0·28	0·23	0·21	0·22
Peritonitis, pneumonia	F	72	0·47	0·33	0·38	0·36	0·21	1	0·36	0·35	0·26	0·21
Pneumonia, cerebrovascular accident	M	72	0·60	0·38	0·36	0·35	0·34	1	0·34	0·39	0·36	0·34

statistics, were performed on a PDP 11/05 computer.

Results

The 10 patients were divided into two groups according to the F_{IO_2} indicated by their clinical condition. The first group was ventilated at F_{IO_2} between 0·21 and 0·3, and the second group at F_{IO_2} between 0·4 and 0·6. Table 1 contains a summary of the shunt values in both groups as measured at the patient's required F_{IO_2} and at $F_{IO_2}=1$.

In fig 1 the influence of PEEP (from 0 to 15 cm H_2O) on Pao_2, $CaCo_2$, a-vDo_2, and intrapulmonary shunt is compared during ventilation with F_{IO_2} between 0·21 and 0·3 and at $F_{IO_2}=1$. In the first instance PEEP has little influence on these values. In the same patients however, the same procedure, but at $F_{IO_2}=1$, resulted in a significant decrease in the intrapulmonary shunt ($p<0·05$).

Figure 2 depicts the results in the five other patients. In this group increased PEEP induced a significant increase of Pao_2 and Cao_2 ($p<0·01$), and a significant decrease in shunt ($p<0·01$) during ventilation with $F_{IO_2}=0·4-0·6$, as well as during ventilation with F_{IO_2} equal to unity (increase in Pao_2 and Cao_2, $p<0·05$, and decrease in shunt $p<0·05$). A slight increase of a-v Do_2 in these patients was not significant at either level of F_{IO_2}.

Discussion

In 1942, Berggren suggested a method of calculating intrapulmonary venous admixture by the inhalation of pure oxygen,[8][9] and thus two of the problems associated with shunt determination were eliminated. By using an increased oxygen concentration, it is possible to avoid the shunt effect caused by the perfusion of partially ventilated alveoli.[4] This method thus allows the

determination of the "true shunt", which is caused by an admixture of venous blood from non-ventilated parts of the lung. The second problem is the difficulty in measuring or calculating the alveolar oxygen concentration, required for intrapulmonary shunt calculations. This can be measured using a fast response oxygen analyser, or calculated using the alveolar air equation. Since fast response oxygen
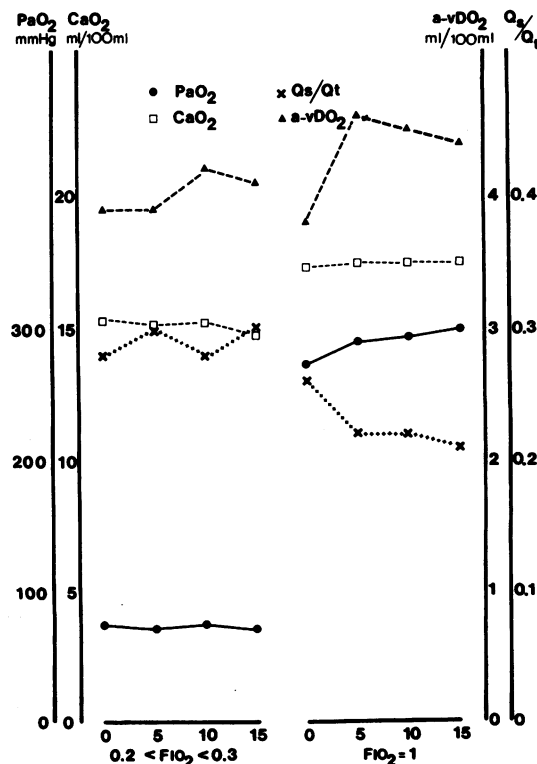

Fig 1 *Effect of PEEP on Pao_2, Cao_2, a-vDo_2, and venous admixture, with an F_{IO_2} value between 0·21 and 0·3 and with $F_{IO_2} = 1$ (mean values of five patients).*
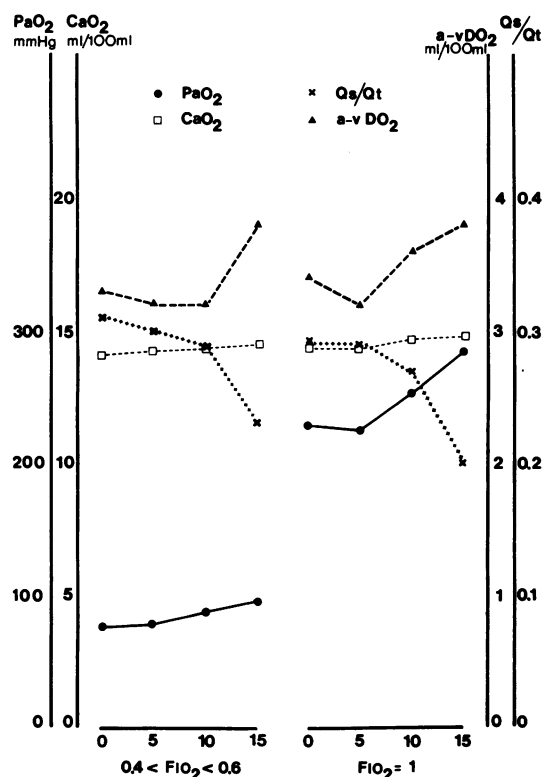
Fig 2 *Effect of PEEP on Pao , Cao , a-vDo ·, and venous admixture, with a FIO₂ value between 0·4 and 0·6, and with FIO₂ = 1 mean values of five patients).*

analysers are not always available and the resolution of the alveolar air equation requires the determination of FEO_2 and $FECO_2$ the use of $FIO_2 = 1$ will greatly simplify calculation for the venous admixture. Indeed, at $FIO_2 = 1$ the "correction factor" $(FIO_2 + (1 - FIO_2)/RQ)$ is cancelled to unity, and the alveolar air equation becomes: $PAO_2 - FIO_2$ $(P_{Bar}-PH_2O) - Pcao_2$. Inhalation of pure oxygen is therefore widely used during venous admixture measurements for clinical and scientific purposes.[10-15] However, it is now well documented that high FIO_2 influences the pulmonary shunt by itself. Several workers found an increase in the pulmonary shunt after high FIO_2 administration, explained by a reduction in the functional residual capacity (FRC)[13][16] because of absorption atelectasis.[10][11][16-20] This inverse correlation between FRC and venous admixture has been demonstrated previously.[21][22] Otherwise, the shunt may decrease when FIO_2 increases.[13] If it

is obvious that variations of FIO_2 modify the value of the shunt, it is also evident that measurements of venous admixture should be performed at the particular FIO_2 inhaled by the patient, as indicated by the clinical status. The clinical value of this form of shunt calculation is also preferable, as it takes into account changes in ventilation-perfusion disturbances when the V/Q ratio is greater than zero.[23][24] The difficulty in calculating the venous admixture with values of FIO_2 lower than unity does not justify shunt measurements with pure oxygen. Moreover, we found that usually another method can be used to eliminate the "correcting factor" for simplifying the alveolar air equation. When FIO_2 is higher than 0·3, one can assume the RQ value as constant and equal to unity, as usual variations of the RQ values cannot modify the calculated shunt. We calculated the venous admixture at the patient's FIO_2 with RQ values varying from 0·6 to 1·4, and it became apparent that only in patients ventilated with an $FIO_2 = 0·21$ did modification of the RQ values influence the calculated venous admixture, while for all FIO_2 values higher than 0·29 venous admixture varied only slightly (table 2). For these reasons, in patients with an enriched concentration of oxygen, which is usually the case, one may assume for purposes of calculation that the RQ is equal to unity, and eliminate the correction factor $(FIO_2 + (1 - FIO_2)/1 =)$. However, in patients breathing room air, or air slightly enriched with oxygen, the shunt has to be calculated using the real RQ values.

Most of the studies on the influence of PEEP on venous admixture were performed on patients ventilated with $FIO_2 = 1$. With few exceptions,[25][26] a decrease in shunt value was usually found with PEEP,[1][2][27-33] correlated with an increased FRC.[2][31-34] Therefore, venous admixture is considered as one of the main factors in evaluating "optimal PEEP".[29] Considering the influence of FIO_2 on the calculated pulmonary shunt found

Table 2 *Influence of respiratory quotient values on the calculated shunt at different levels of FIO·. Patients were divided according to their FIO·, and mean pulmonary shunt of each group was calculated, using the measured blood gas values and assuming values of RQ varying from 0·6 to 0·4*

F_{IO_2}	RQ 0·5	0·8	1	1·2	1·4
0·21	0·23	0·26	0·28	0·29	0·29
0·29–0·30	0·31	0·32	0·32	0·32	0·32
0·40–0·41	0·24	0·25	0·25	0·25	0·25
0·47–0·60	0·34	0·34	0·34	0·34	0·34

in our patients, it is questionable, however, whether the observed influence of PEEP on venous admixture at FIO_2 equal to unity reflects the effect of PEEP at lower levels of FIO_2.

In this study PEEP had no influence on venous admixture at low levels of FIO_2 (0·21–0·3), suggesting that PEEP has little value in patients who can be ventilated at this FIO_2. The significant reduction in venous admixture produced by PEEP in the same patients at $FIO_2 = 1$ demonstrates that, in order to evaluate the real effect of PEEP on venous admixture as a guide to therapy, measurements have to be carried out at the patient's required FIO_2. At higher levels of FIO_2 the influence of FIO_2 variations on the PEEP effect is apparently less important; the reduction in venous admixture obtained with PEEP in patients ventilated at $FIO_2 = 0·4–0·6$ as similar to that observed when they were ventilated at $FIO_2 = 1$.

We have shown that the influence of PEEP in our patients varied with the value of FIO_2, and that its effect on pulmonary shunt was absent when FIO_2 was lower than 0·3. Assuming that PEEP increases FRC, while high FIO_2 decreases it, the beneficial effect of PEEP at high FIO_2 could be partially explained by the reduction of this side effect of the high FIO_2, but further ventilation-perfusion alterations as well as variations in pulmonary resistance and pulmonary fluid content must be considered. It is possible that for special situations, as in pulmonary oedema or drowning, PEEP could be effective at low FIO_2, but none of our patients had these conditions.

In summary, our results suggest that PEEP does not influence the intrapulmonary shunt at low levels of FIO_2 (0·21–0·3). When FIO_2 is greater than 0·3 the calculation of venous admixture can be simplified by neglecting the "correction factor" of the alveolar air equation.

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