Current Comment

S. G. HERSHEY, M.D., *Editor*

Inspired Oxygen Concentration Delivered by the Bird Ventilator

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The Bird Mark 7 Respirator has been shown to deliver higher than expected oxygen concentrations when oxygen is used as the driving gas.[1] This is an inherent feature of the incorporated air entrainment device which functions in such a way that, as the pressure rises in the ventilator-lung system, less air is entrained and inspired oxygen level increases. The problem is greatest at the higher cycling pressures and at the lower peak inspiratory flow settings.

It has been suggested that one might use compressed air as the driving gas and enrich this with oxygen, added on either the ambient or pressurized side of the machine (fig. 1). A study of the performance of the Bird Mark 7 Ventilator when operated in this manner was undertaken and is the subject of this report.

METHOD

One might anticipate that the important variables would be the volume flow of oxygen added to the machine, the total flow of gases delivered on inspiration (peak inspired flow rate) and the effect of cycling pressure on the performance of the entrainment device. To examine these variables, each of the two ventilators studied was connected to a mechanical analogue of the human lung-thorax in such a way as to simulate clinical circumstances (fig. 2).

The expiratory valve pressurising line was not led back into the circuit and was clamped distal to the valve. Concentration of oxygen in the inspired air was examined under the following circumstances: a motive force consisting of compressed air at 50 psi, peak inspiratory flow rates of 20, 40, 60 and 80 liters /minute, cycling pressures of 5, 10, 20, 30, 40, 50 cm. of water and oxygen delivered to either the ambient or pressurized side of the ventilator at flows of 1, 3, 5, 7 and 9 liters/minute. The expired gas was collected in a 100-liter Douglas Bag and this was taken to represent mean inspired gas. Peak inspiratory flow rate was measured using a Fleisch no. 2 pneumotachograph and Statham PM 5 differential transducer connected between the ventilator and the analogue. Cycling pressure was detected by a Statham R23 transducer. Both were recorded on a Grass Model 5 Polygraph. The analogue was ventilated for 20 minutes once peak flows and pressures were set and oxygen added appropriately. The Douglas bag was filled and rinsed once before being filled for the measurement. Mixed expired gas samples were then collected in two greased 50 ml. syringes after they had been

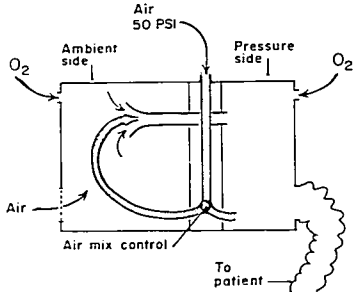

FIG. 1. Diagram of Bird Mark 7 Ventilator showing division into ambient and pressurised sides. The ventilator is driven by air with oxygen added to either side.

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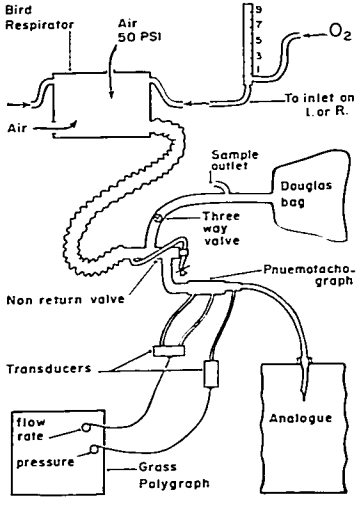

FIG. 2. System used for evaluation of ventilators.

rinsed to clear the dead space. Oxygen tension was measured immediately using a Radiometer P_{O_2} electrode. The oxygen percentage was calculated for each measurement using the formula $F_IO_2 = \frac{P_{O_2}\ (\text{measured})}{\text{B.P.} - 47}$.

RESULTS

Oxygen added to the ambient side of the ventilator. Individual values and means are shown in table 1. At any given added oxygen flow rate, inspired oxygen concentrations decrease as cycling pressure is raised. An example of this is shown in figure 3, depicting values obtained at a peak inspiratory flow rate of 60 liters/minute. At levels commonly used in clinical practice, peak inspired flow rate had little effect on inspired oxygen concentration (fig. 4).

Oxygen added to the pressurized side of the ventilator. Table 2 shows individual values and means obtained for oxygen concentrations delivered under these circumstances. Although high oxygen concentrations are delivered at very low cycling pressures, this is a peculiarity of the experimental circumstances whereby the added oxygen accounted for a high proportion of the inspired volume, when cycling occurred quickly. In the clinical cycling pressure range, inspired oxygen concentrations rise at the high cycling pressures—presumably due to falling air entrainment (fig. 5). As with values obtained when oxygen was added to the ambient side, changes in inspired flow rate within the commonly used range produced little change in inspired oxygen concentrations (fig. 6).

The two ventilators examined in this study did not have the expiratory valve pressurising

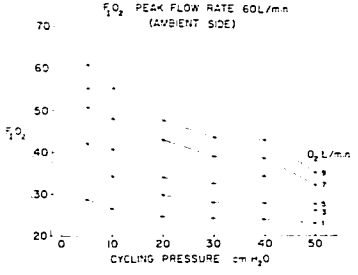

FIG. 3. Mean inspired oxygen concentrations obtained for various flows of oxygen added to the ambient side of the ventilator, at a peak inspired flow rate of 60 liters/minute.

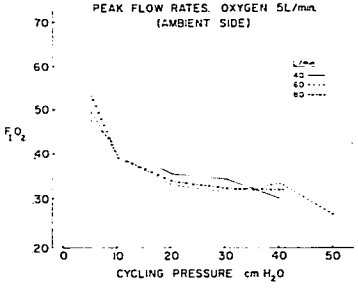

FIG. 4. Effect of inspiratory flow rate on mean inspired oxygen level. Oxygen added to ambient side of ventilator at 5 liters/minute.

TABLE 1. Values for Inspired Oxygen Concentration Delivered by Two Ventilators at Various Cycling Pressures and with Various Flows of Oxygen Added to the Ambient Side

Added O_2 (L./min.)	1						3						5						7						9					
Cycling pressure (cm. H_2O)	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50
Peak Flow Rate 20 Liters/Minute																														
F_IO_2 Ventilator A	.312	.296	.271				.479	.386	.344				.534	.445	.370				.577	.508	.401				.657	.618	.445			
F_IO_2 Ventilator B	.302	.289	.291				.464	.429	.314				.550	.487	.364				.570	.515	.404				.662	.614	.416			
F_IO_2 Mean	.307	.293	.281				.472	.407	.329				.542	.466	.367				.578	.512	.404				.660	.616	.430			
Peak Flow Rate 40 Liters/Minute																														
F_IO_2 Ventilator A	.318	.274	.250	.240	.243		.453	.378	.322	.306	.258		.523	.437	.353	.347	.326		.572	.471	.433	.378	.357		.646	.522	.460	.422	.387	
F_IO_2 Ventilator B	.265	.265	.257	.254	.255		.370	.337	.325	.313	.273		.452	.413	.374	.358	.293		.520	.482	.422	.403	.310		.578	.516	.484	.444	.327	
F_IO_2 Mean	.291	.270	.254	.247	.249		.412	.358	.324	.310	.266		.488	.425	.364	.353	.310		.546	.477	.428	.391	.334		.612	.519	.472	.433	.357	
Peak Flow Rate 60 Liters/Minute																														
F_IO_2 Ventilator A	.291	.271	.242	.243	.233	.216	.425	.336	.293	.283	.279	.233	.480	.403	.337	.322	.338	.247	.534	.476	.439	.412	.391	.303	.613	.574	.480	.448	.420	.342
F_IO_2 Ventilator B	.283	.262	.252	.242	.247	.244	.418	.350	.303	.276	.275	.279	.525	.413	.345	.328	.348	.298	.571	.486	.422	.370	.378	.338	.604	.530	.473	.424	.437	.358
F_IO_2 Mean	.287	.267	.247	.243	.240	.230	.422	.343	.298	.280	.277	.258	.507	.408	.341	.325	.343	.273	.553	.481	.431	.390	.385	.321	.609	.552	.477	.436	.429	.350
Peak Flow Rate 80 Liters/Minute																														
F_IO_2 Ventilator A	.305	.269	.247	.244	.233		.451	.367	.288	.283	.275		.536	.427	.372	.333	.318		.618	.434	.393	.376	.336		.643	.504	.415	.406	.397	
F_IO_2 Ventilator B	.300	.267	.242	.241	.247		.436	.313	.288	.280	.297		.549	.381	.327	.333	.341		.604	.455	.365	.371	.366		.611	.481	.406	.415	.415	
F_IO_2 Mean	.303	.268	.245	.243	.240		.444	.340	.288	.282	.286		.543	.404	.350	.333	.330		.611	.445	.379	.374	.351		.627	.493	.411	.411	.406	

TABLE 2. Values for Inspired Oxygen Concentrations Delivered by Two Ventilators at Various Cycling Pressures and with Various Flows of Oxygen Added to the Pressurised Side

Added O_2 (L./min.)	1						3						5						7						9					
Cycling pressure (cm. H_2O)	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50	5	10	20	30	40	50
Peak Flow Rate 20 Liters/Minute																														
F_IO_2 Ventilator A	.360	.335	.290				.506	.435	.385				.626	.494	.508				.711	.586	.587				.768	.657	.640			
F_IO_2 Ventilator B	.322	.311	.308				.473	.401	.408				.605	.511	.445				.640	.561	.550				.710	.626	.598			
F_IO_2 Mean	.341	.323	.299				.490	.418	.397				.616	.503	.477				.676	.574	.569				.744	.642	.619			
Peak Flow Rate 30 Liters/Minute																														
F_IO_2 Ventilator A	.280	.281	.251	.230	.230		.398	.327	.324	.299	.299		.491	.393	.398	.341	.359		.570	.473	.462	.413	.555		.635	.507	.487	.449	.603	
F_IO_2 Ventilator B	.263	.265	.247	.247	.230		.361	.334	.295	.295	.297		.446	.409	.357	.325	.490		.543	.443	.420	.420	.577		.609	.506	.466	.499	.630	
F_IO_2 Mean	.272	.273	.249	.238	.235		.380	.331	.310	.297	.298		.469	.401	.378	.333	.424		.560	.458	.441	.417	.566		.622	.507	.477	.474	.611	
Peak Flow Rate 60 Liters/Minute																														
F_IO_2 Ventilator A	.358	.261	.249	.241	.259	.295	.467	.322	.301	.315	.355	.405	.550	.409	.340	.371	.433	.491	.642	.476	.392	.446	.513	.547	.704	.495	.432	.483	.557	.593
F_IO_2 Ventilator B	.275	.247	.245	.233	.233	.253	.340	.307	.288	.285	.286	.388	.442	.382	.340	.338	.341	.491	.521	.429	.400	.431	.478	.568	.568	.451	.437	.459	.555	.615
F_IO_2 Mean	.317	.254	.247	.237	.246	.274	.404	.315	.295	.300	.321	.397	.501	.396	.348	.355	.387	.491	.583	.453	.396	.438	.496	.558	.636	.473	.435	.471	.556	.604
Peak Flow Rate 80 Liters/Minute																														
F_IO_2 Ventilator A	.287	.274	.242	.259	.240		.378	.316	.290	.282	.325		.461	.372	.320	.345	.401		.545	.437	.391	.396	.454		.663	.484	.429	.435	.470	
F_IO_2 Ventilator B	.311	.264	.242	.245	.237		.452	.351	.280	.284	.345		.581	.397	.298	.314	.439		.645	.468	.367	.370	.552		.726	.518	.400	.405	.582	
F_IO_2 Mean	.299	.269	.242	.252	.239		.415	.334	.285	.283	.335		.521	.385	.314	.330	.420		.595	.453	.379	.383	.503		.695	.501	.415	.421	.526	

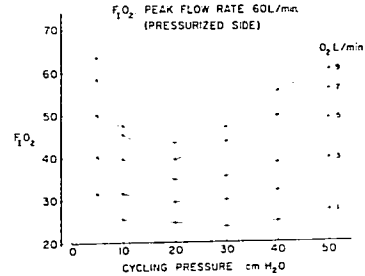

FIG. 5. Mean inspired oxygen concentrations obtained for various flows of oxygen added to the pressurised side of the ventilator.

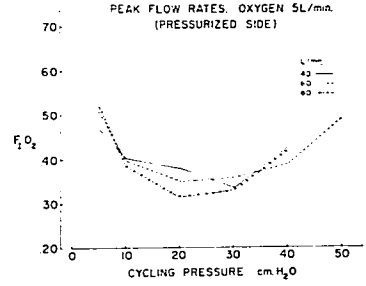

FIG. 6. Effect of inspiratory flow rate on mean inspired oxygen level. Oxygen added to pressurised side of ventilator at 5 liters/minute.

line led back into the circuit. In instances where this line is used for nebulization, the effect would be to add a small quantity of the driving gas to the inspired mixture. The overall effect would be a very small reduction in inspired oxygen concentration.

DISCUSSION

Anxiety has been expressed that the prolonged administration of high concentrations of inspired oxygen may produce pulmonary damage.[2, 3] Since maximum increase in arterial oxygen saturation, in patients with pulmonary disease, can usually be produced by using inspired oxygen concentrations well below 50 per cent, the results obtained in this and our previous study [1] suggest that the Bird Mark 7 Ventilator may best be operated from a source of compressed air, with the addition of oxygen to the ambient or pressurized side. Considerable variation occurs between individual ventilators, but oxygen concentrations between 21–45 per cent can be obtained by adding oxygen at flows up to 9 liters/minute.

The tendency is for inspired oxygen levels to be lower at high cycling pressure when the oxygen is added to the ambient side of the machine. Although this may be avoided by adding the enriching oxygen to the pressurized side, this interferes with patient triggering at the higher oxygen flows. In practice, it is useful to measure oxygen levels at the tracheotomy. In the very occasional case where adequate oxygenation cannot be achieved by this means, the ventilator should be operated from a source of compressed oxygen.

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