Are Babies in Carry Cots at Risk from CO₂ Accumulation?

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On 26 October 1971 Dr David Haler, a pathologist, is reported as having said in evidence on a case of cot death in a carry cot "There is no ventilation in a carry cot, so carbon dioxide which is heavier than air sinks to the base of the cot where the child is sleeping" (*Oldham Evening Chronicle*, 27 October 1971).

To clear up a possible misconception implicit in this opinion, it must be pointed out that if individual gases in a mixture settled out according to their densities the atmosphere would be stratified into a very thin layer of carbon dioxide at ground level, then a layer of pure oxygen up to a few thousand feet, with the upper air composed of nitrogen. But, on the other hand, a given mixture of gases will rise or fall when introduced into the atmosphere depending on whether the density is greater or less than that of the surrounding air. Ultimately, of course, diffusion will complete the mixing of these gases with the surrounding atmosphere.

The possibility remains that this diffusion is slow enough to allow the carbon dioxide, nitrogen, and oxygen mixture that a baby expires to pool in the base of a carry cot.

We investigated the possibility of such an occurrence, and although we concluded that there is no such possibility we think it necessary to report the results, not only to enable medical practitioners to reassure mothers but also to record how alarming some of the preliminary experiments were. We wish to spare any future investigators these alarms

Methods and Results

The first series of investigations were performed using a model baby lying in a variety of receptacles of different materials. The constitution of the model is shown in Fig. 1.

FIG. 1—Model of the respiratory system (see text).

CO₂ was introduced continuously into the "lungs" of the model at a rate of 60 cm³/min. They were ventilated by a sine-wave pump whose rate and stroke volume were continuously variable. For most of the runs the frequency was 60 strokes/min and the stroke volume 25 cm³, but these figures were on occasion altered greatly and found to be uncritical. The connexion to the exterior, the "dead space," was a piece of Portex vinyl tubing 25-cm long with an internal volume of 8 cm³. The distal end was divided by zinc oxide plaster into two "nostrils" with a combined cross sectional area of 0.2 cm². The tip of the catheter which drew off air to the gas analyser was situated in the "nasal septum."

This contrivance running in the open gave a very convincing trace of CO₂ percentage at the nostril, with the level rising to an "alveolar" plateau of 5-6% during the expiratory phase and dropping sharply to 0 in the inspiratory phase.

When the model was placed in a box open at the top CO₂ build-up occurred, as evidenced by the level recorded during the inspiratory phase. If the box were of cardboard or canvas the rise was trivial, but if the box were acrylic or polyvinyl chloride (P.V.C.), the rise was continuous to over 10%. The "minute volume" of the model altered the plateau levels on the expiratory phase, but had no detectable effect on the rate of rise of the inspiratory CO₂ level. This, of course, depended entirely on the CO₂ flow rate from the cylinder through a rotameter.

We then placed the model in a canvas labour ward bassinet which was 40 cm deep. The top was sealed off completely with polyvinyl chloride with the model running inside, and the CO₂ level rose to less than ½%. Extra CO₂ was squirted into the bassinet so that the level reached 3%; this fell back ½% within two minutes. Similar results were obtained with a "cocoon" of quilted Terylene in which the model's "head" was placed in the blind end of this baby carrier.

The carry cots were made of, or lined with polyvinyl chloride, and in them we placed a large doll with the model strapped to its back and the dead space tube curving over the head and taped to the nose. The doll was placed on its side and tucked in with sheets and blankets.

In this situation the inspired CO₂ rose steadily to levels of 8 or 9% over periods of 1-3 hours, and it made little difference whether the hood was up and the polyvinyl chloride cover up to the base of the hood was attached. The CO₂ was clearly "pooling" in the bottom of the carry cot and rising to "lethal" levels.

The time course of carbon dioxide accumulation is shown in Fig. 2. Intermittent draughts caused noticeable but transient changes in the CO₂ levels at the position of the sampling catheter. So there was considerable irregularity superimposed on the steady rise of carbon dioxide content in the carry cot.

The original dead space of the model was a simple polyethylene tube with a cross-sectional area of 0.32 cm². The air speed at the end was therefore relatively slow. The addition

FIG. 2—Accumulation of CO₂. A, When model was in carry cot without doll. B, Repeat situation of A. C, Doll in carry cot with model attached, before introduction of "nostrils." D, Doll in carry cot with model attached, and "nostrils" now introduced. E, Doll with model attached, placed in canvas bassinet with polyethylene sheet covering top. Dotted line shows effect of blowing in large amounts of 6% CO₂ from a cylinder.

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Calculation of Density of Relevant Gas Mixtures

	O ₂		N ₂		CO ₂		H ₂ O		Total Weight*	Density at 760 mm Hg (g/l.)
	%	Weight*	%	Weight*	%	Weight*	%	Weight*		
Air:										
20°C dry	21.00	6.72	79.00	22.12	—	—	—	—	28.84	1.200
35°C dry	21.00	6.72	79.00	22.12	—	—	—	—	28.84	1.141
35°C 50% humid ..	20.45	6.54	76.90	21.54	—	—	2.63	0.47	28.55	1.130
End-expired air of:										
20°C dry	19.74	6.32	74.26	20.79	6.00	2.64	—	—	29.75	1.237
Model { 20°C dry ..	19.74	6.32	74.26	20.79	6.00	2.64	—	—	29.75	1.170
37°C dry	18.52	5.93	69.67	19.51	5.63	2.48	6.18	1.11	29.03	1.130
37°C wet	13.13	4.20	75.06	21.02	5.63	2.48	6.18	1.11	28.81	1.122
Baby 37°C wet ..										

* Weight in g/22.4 l. at standard temperature and pressure.

of "nostrils" (narrowing the final cross section) should increase the air speed and to some extent project the expirate away from the model, lessening "rebreathing" and mixing the gases in the carry cot. There was some diminution in the rate of

carbon dioxide build up, shown in the difference between lines C and D in Fig. 2, but the final levels were not reduced to any degree.

FIG. 3—Accumulation of CO₂ over period of 16 hours when model, attached to doll in carry cot, was cold. At A heater switched on, and at B heater switched off and water at room temperature run into heat exchanger.

FIG. 4—Comparisons of model with live baby.

MODIFIED MODEL

The model was then modified by incorporating a heat exchanger on the airline from the pump, and water at 35°C was circulated around a flanged copper tube, which transmitted the alternating air flow to the mixing chamber of the model. This was also placed on the back of the doll and wrapped around with bedding.

So the model was now "expiring" warm gases and was also itself warm.

The results from using this modification are shown in Fig. 3.

A final series of experiments showed that if the model were only 3°C warmer than the room this would prevent any accumulation of CO₂ above 1.5% CO₂. Further, if the air was humidified by injecting distilled water on to gauze within the mixing chamber at a temperature of only 1-2°C above the room temperature (about 30°C), CO₂ levels rapidly fell to below 0.5%.

The humidity in our heated laboratory was, of course, low, but the results bear out the theoretical effect of adding water vapour to a CO₂/air mixture (see Table).

Conclusions

We conclude that unless a baby is cooler than the wet bulb temperature of its surroundings (an intolerable thermal stress) convection of its expired air will prevent any accumulation of carbon dioxide, even in closely confined CO₂-impermeable receptacles.

We have recorded CO₂ percentages at the nostrils of three sleeping babies in bassinets and carry cots. The inspired CO₂ has not exceeded 0.2% in observations up to six hours in length (Fig. 4).

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