Effects of Obstruction to Respiration in Infants, with Particular Reference to Mattresses, Pillows, and their Coverings

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Summary : A comparison was made of pillows of various designs and their effects on the flow of air through the respiratory tract of six children who had been found dead in their cots. The effects of alterations in posture and of soaking the pillow with milk were also studied.

There was a wide variation in the obstruction to air flow in pillows of different design. A firm pillow which allows air and fluid to pass through it is best, and is probably superior to a mattress covered with a mackintosh and a sheet.

External obstruction to respiration could be a contributory factor in some cases of cot death.

Introduction

This investigation was stimulated by inquiries for guidance on the advisability of having different types of pillows for children. The easy answer to this question is that pillows are not necessary at all, but then what evidence have we that a soggy mattress is any better than an airy pillow, or, indeed, that mattresses and pillows can cause a child to suffocate?

As part of the general problem of unexpected death in childhood the question of smothering when the child lies face down on the pillow or is smothered by the bedclothes is often raised. We have always investigated this point in dealing with these deaths and have found no convincing increase in children lying face down as distinct from face up when found dead in their cots as compared with the proportion of children who normally sleep prone or supine (Emery, 1959). This finding has led us to suspect that the posture of the child and the position of the bedclothes may have very little effect, but until the problems of unexpected infant deaths have been solved, which is likely to take many years yet (Wedgwood and Benditt, 1966), the possibility of a child being smothered in its cot by becoming suffocated through lying face down in the pillow will continue to worry every parent (Abramson, 1944).

Opinions on this matter abound, but we could find no evidence. For that reason we thought it advisable to carry out some experiments on children who had actually been found dead in their cots. Our aim was to try to reproduce the breathing pattern in these cases by passing the child's tidal air upwards from the larynx through the nose and mouth and record possible obstructions to the flow of air by actions such as movement of the tongue or neck, obstructing the nostrils, or placing the child face down on a variety of pillows and mattresses.

The bedding tested in this way consisted of the ordinary hospital sheets and pillows, and, in addition, special pillows and mattresses that have been put on the market as relatively safe for use with children. We therefore wrote to as many manufacturers of mattresses and pillows as we could locate. All of them were immediately responsive and sent us samples of their wares. It was quite obvious that the makers had been concerned in producing what they felt were the safest

types of bedding for infants, and that much thought and ingenuity had gone in designing them. Descriptions of these pillows are given in an Appendix.

Method

The resistance to ventilation can be represented by

$$\text{Resistance} = \frac{\Delta P \text{ (cm. water)}}{V \text{ (litres/sec.)}}$$

where ΔP is the difference in pressure measured between the point X in the airway and the atmosphere (see Fig. 1), and V is the volume of gas per unit time (in this case ml./sec.). The resistance will vary with the volume of gas flowing at any one moment in time (flow rate). As this flow rate is a function not only of the airway resistance but also of the type of ventilator, the pressure fluctuates with the "respiratory cycle." In view of the fact that the flow rate was not simultaneously and continuously recorded along with the pressure changes it was not possible to quantitate the resistance. However, with a constant volume and respiratory rate any changes of pressure consequent on alteration in the position of the head and type of pillow reflected an alteration to resistance.

FIG. 1.—Diagram of the experimental system used on the cadaver; for description see text.

The subject was ventilated with a Starling pump, which delivers a sinusoidal flow rate pattern. The rate and tidal volume were determined from a knowledge of the subject's weight, Radford's (1955) Nomogram being used, and this setting remained constant throughout the investigation.

The upper respiratory tract was connected to the Starling pump in the following manner. The child's chest was opened and the lower end of the trachea exposed, and, after firmly fixing, an endotracheal tube of the largest possible internal diameter was inserted from the lower end of the trachea, so that the tip of the catheter lay just below the vocal cords. The armoured Magill endotracheal tubes used were those used for anaesthesia. The tube was then connected at its lower end to the Starling ventilator (see Fig. 1), and a small T-junction enabled a differential pressure manometer (New Electronics Products Inductance Type 1028) to be attached. An amplifier (N.E.P. Type 644/13) enabled the signal to be recorded on

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Servoscribe Potentiometric Recorder (Type Re511). A continuous recording of pressure changes was noted throughout the investigation.

After the catheter had been firmly fixed the sternum was replaced in its original position and the whole of the cadaver was sewn up with the tubes emerging from the upper abdomen (Fig. 2). The mouth and air passages were sucked clear of debris, mucus, and fluid.

The following movements were carried out:

(1) The child was left on its back and the effect noted of (a) opening and closing the mouth, (b) pulling the tongue forward and allowing it to fall backward, and (c) closing one or both nostrils.

(2) The child's face and head were rolled over from one side to the other on a variety of surfaces and materials.

FIG. 2.—Photograph of the procedure used in the mortuary.

(3) The child was turned on to its face and the effect noted of (a) placing the infant face down on to the slab, (b) placing its face in a small pool of milk, and (c) positioning the head on either side.

(4) The child was then held in a horizontal position and the head allowed to fall smoothly and evenly directly downwards on to a variety of pillows and mattresses and the effect noted of (a) the head being placed directly nose down in the centre of the mattress and left in this position, it being pressed into the mattress only by its own weight; and (b) after readings had been stabilized 30 ml. of milk (half-cream Cow and Gate obtained from the hospital milk kitchen) taken from a feeding-bottle was poured into the depression produced by the child's face and the effect of this was allowed to be seen on the pressure trace. In some instances further aliquots of milk were added. After varying lengths of time, depending on the reaction to this, the head was turned to the side and the nose and throat were thoroughly aspirated until completely free before carrying out a test with the next mattress or pillow.

Six infants aged 6 weeks to 9 months were examined in this way.

Results

Tests were done on six children. The findings varied quantitatively but showed complete qualitative uniformity, and it was thought pointless to continue studies on further children.

Opening and Closing Mouth and Nose

With the child in any position and with the nose clear, opening and closing of the mouth had no effect on air flow. With the mouth closed, opening and closing one nostril also had no effect. This is shown in Fig. 3. It is seen that closing the mouth and then also closing one nostril had no effect on the pressure sequence. In all of the children studied it was found that when the nose and mouth passages were clear one (either) nostril alone permitted completely free passage of air.

Closing both nostrils had no effect provided the mouth was open and the tongue in a resting position.

The normal cadaveric position of the tongue does not appear to obstruct air flow in any way, but when cadaveric rigidity is broken down and the tongue falls back, resting on the back of the throat, obstruction is produced. This obstruction is

FIG. 3.—Tracing while the child lay in the supine position, the nose and mouth being open at O. The mouth was closed by lifting the chin at M and one nostril was closed at N. It made no difference which nostril was closed.

greater to inspiration than to expiration. The tongue appears to act as a ball valve, allowing the emission of air but not its entry.

Prone Face on Hard and Firm Surfaces

The hard surface used was the marble slab of the necropsy table and the firm surface a large hospital pillow which consisted of a tightly filled plastic bag with a closely adherent linen ticking—that is, having the characteristics of a mattress.

The effect of the weight of the child's head on its nose on a dry slab is shown in tracing A in Fig. 4, where it is seen that a small increase in resistance occurred. This varied in different babies, and the one illustrated showed more than usual. A slight change was noted in all. It is relevant to note that in some preliminary technical studies we did on much older children no impediment was seen in this position owing to the more firmly developed structure of the older nose.

FIG. 4.—Tracing produced where the child's head was lowered on to a plain slab (at A), the weight of the child's head being on its nose and mouth. The head was lifted and then lowered on to a small dish of milk about 5 mm. deep (at M). The head was lifted after eight respirations.

The changes seen when the head was lowered on to the firm pillow were greater than those on the plain slab. Fig. 5

shows the effect of lowering the face on to the hard pillow when the linen ticking was both dry and damp—the linen had no free fluid, and there was no pool of milk or water in the concavity produced by the child's head. A similar effect was seen when the child's head was rolled over on to its face

FIG. 5.—Tracing showing the effect of lowering the child's head on to a dry (at D) and damp (at W) firm hospital pillow having the consistency of an ordinary mattress. The pillow was covered with a tight-fitting linen slip made of sheeting and there were no pools of fluid on its surface.

and then on to the other side (see Figs. 6 and 7). Both manœuvres produced some degree of obstruction to air flow, the moist linen a little more than the dry. More obstruction was produced in all cases than when the child's face was rolled over on the marble slab.

Effect of Milk Alone

To test the effect a shallow trough of milk was used, so that when the baby's face went into it the milk was no more than 5 mm. deep. The result of this manœuvre is shown in Fig. 4, where the effect of the face on the underlying slab is also shown. The milk produces considerable obstruction. The effect seemed to diminish, presumably largely owing to the milk being "spluttered" away.

Effect of Pillows from Manufacturers

The results of placing the head face down and then adding 30 ml. of milk into the hollow produced by the face on a variety of pillows are shown diagrammatically in Fig. 10, and the numerical values of the effects on pressure excursion in the system are given for two children in the Table.

It is obvious that the effects of different pillows were variable. Some produced a great deal of obstruction in the dry state; these were chiefly soft pillows. The effect of the milk depended on the rapidity with which the pillow cleared itself.

FIG. 6

FIG. 7

FIGS. 6 and 7.—Tracings produced when the child's head was slowly rolled over on its face from one side to the other. Note the gradual increase in obstruction as the head became vertical. On this occasion the damp pillow (Fig. 7) showed relatively greater resistance than the dry (Fig. 6) than in the child shown in Fig. 5. The same pillow was used in each case.

Percentage Increase in Pressure Above Normal Unobstructed Values

Pillow No.	Inspiration	Change	Expiration	Change	Total	Change
Subject A						
1 { Dry	1,900%		2,300%			
Wet	3,500%	80%	900%	-58%		+15%
2 { Dry	2,100%		400%			
Wet	3,500%	64%	1,100%	+140%		+78%
3 { Dry	900%		400%			
Wet	3,500%	260%	900%	+100%		+206%
4 { Dry	2,000%		400%			
Wet	3,500%	70%	600%	+100%		+76%
5 { Dry	3,500%		900%			
Wet	3,500%	0%	1,100%	+20%		0%
6 { Dry	900%		1,500%			
Wet	3,300%	240%	700%	-50%		+17%
7 { Dry	900%		1,900%			
Wet	3,500%	280%	900%	-50%		+53%
8 { Dry	1,100%		2,100%			
Wet	2,900%	150%	900%	-54%		+176%
9 { Dry	700%		1,100%			
Wet	700%	0%	1,100%	0%		0%
10 { Dry	1,500%		2,100%			
Wet	3,500%	130%	1,100%	-46%		+26%
Subject B						
1 { Dry	2,500%		78%		1,800%	
Wet	2,500%	0%	1,600%	40%	1,780%	9%
2 { Dry	940%		220%		580%	
Wet	2,300%	139%	540%	100%	1,420%	130%
3 { Dry	940%		380%		660%	
Wet	2,140%	120%	540%	33%	1,540%	90%
4 { Dry	2,580%		700%		1,543%	
Wet	2,580%	0%	700%	0%	1,640%	0%
5 { Dry	2,700%		460%		1,589%	
Wet	2,780%	2.8%	540%	30%	1,660%	4.8%
6 { Dry	0%		0%		0%	
Wet	1,900%	1,900%	400%	20%	960%	2,060%
7 { Dry	2,580%		180%		1,380%	
Wet	2,500%	0%	620%	157%	1,620%	15%
8 { Dry	80%		80%		80%	
Wet	2,550%	1,390%	540%	260%	1,560%	820%
9 { Dry	140%		140%		140%	
Wet	140%	0%	180%	0%	160%	5%
10 { Dry	2,100%		2,600%		1,180%	
Wet	2,460%	16%	7,800%	140%	1,620%	33%

Details of a fairly typical reaction of a poor pillow are shown in Fig. 8, obtained from pillow No. 2. Here the face-down position (d) produced a fivefold increase in pressure excursion, which gradually diminished to about fourfold after about 30 "breaths." This "tailing-off" was a fairly consistent feature and appeared to be due to the setting-up of air channels around the child's face. When the 30 ml. of milk was added (w) an immediate increase in resistance occurred, then showed a similar fall-off over about 20 breaths and became stable, to be relieved when the child's head was turned on to its side(s).

In Fig. 9 is shown a tracing from what appeared to be by far the least obstructive pillow, together with the tracing from the next pillow tested. This pillow (No. 9) produced, if any-

FIG. 8

FIG. 9

FIG. 8.—Fairly typical response in a test pillow (pillow No. 2). At point "d" the head was lowered face downwards on to the centre of the pillow. After 70 respirations 30 ml. of milk was poured into the hollow around the face (at "m"). After a further 60 respirations (at "s") the child's head was turned on to its side and then lifted.

FIG. 9.—Successive tests with the same child on two pillows (Nos. 9 and 10). The head was lowered on to the pillow at point "d," the same amount of milk added at "m," and the child's head turned on to its side at point "s." Pillow No. 9 was by far the least obstructive of those studied and appeared to show less obstruction than when the child's head was on the slab or on the mattress-like hospital pillow.

thing, less obstruction to airflow than with the child's face direct on to a hard slab. When the milk was added it immediately ran through the pillow and away. From further studies on this pillow we found that two more aliquots of milk could be added before obstruction occurred. Obstruction then was due to the milk being unable to get away from the mattress underlying the pillow. This pillow was similar in construction to another pillow, but the latter was so thin that the weight of the child's head completely compressed it, and thus, while made of ideal materials, it seemed to be more obstructive than many others.

The methods used in these tests are open to criticism, and, while the tidal volumes and materials used fitted the physiological states so far as is possible, the results and effects of various postures can be considered only on a relative basis and within the limitations of the technique employed.

FIG. 10.—Relative increases in the pressures on two children (Subject A and Subject B) on dry pillows and pillows with milk added, 10 different types of pillow being used.

Points from the Study

However, the following points emerge from this study: (1) Opening and closing the mouth produced no marked alteration in pressure change (see Fig. 3). (2) If the tongue was allowed to fall back into the nasopharynx, then, as would be expected, apparent complete obstruction to the air passages occurred. (3) Closing one nostril and the mouth did not appear to impede air passage. (4) If the mouth was left in a neutral position when both nostrils were closed there was complete obstruction to inspiration but expiration was not affected—that is, the tongue appeared to act as a type of ball-valve. In order to prevent expiration it was necessary to close both nostrils and force the lips together. (5) Turning the head on either side caused no obstruction. (6) A shallow pool of milk caused considerable obstruction. (7) Putting the face downwards on any type of mattress or pillow, with the notable exception of one type, produced varying degrees of impairment of air passage.

In general, the softer the material the more obstruction, and the more board-like the material the least obstruction. The effect of the various types of pillows and mattresses showed that only one type of pillow (No. 9) appeared to be any better than the ordinary hospital pillow, and this pillow had the following characteristics: its covering consisted of a loose mesh having a large number of small holes nearly 1 mm. in diameter. The contents of the pillow consisted of a large number of curled plastic pieces forming a loose slightly springy network of a texture not unlike the old horsehair pillows. This loose network freely permitted milk and fluid to run directly through.

One other type of pillow had something of these characteristics but was thin, so that it did not permit fluid to run away from its underside through the underlying material.

The ideal pillow and mattress for a child should have the following characteristics: (1) it must adequately support the child and allow heat insulation; (2) the child must have complete freedom of respiration no matter in what direction the head is turned; (3) if the child vomits, even in a prone position, the fluid vomit must be able to flow directly away, producing no respiratory obstruction; and (4) the appliance must be hygienic—that is, must be capable of being washed or must be freely disposable.

Having drawn up these criteria, the first thing we thought of that would constitute an ideal mattress for a child was to put it in a hay- or straw-filled manger; or, if one is to be more sophisticated, to lay it on an old sack half-filled with straw or hay.

If one believes that the amount of obstruction to airflow that we have recorded is of importance, then the question that we asked concerning whether a pillow is a good thing or not must be answered in the affirmative, provided it has the characteristics we have listed above, because a mattress covered with a mackintosh and sheet will produce more obstruction than the same mattress with a good pillow. It is impracticable to have a daily washable mattress, though such a pillow is quite possible.

The danger of milk pooling on the surface of pillows and mattresses suggests that the ordinary sheeted cot mattress should not be level but be placed at such an angle that any fluid will run away. It is interesting to note that one pillow manufacturer was aware of this and ensured that the surface of his pillow was always at an angle by incorporating a firm roll within one side.

Conclusion

The question that remains is, what importance, if any, does the degree of respiratory obstruction we have measured have in causing unexpected death in infants? There is now little doubt that acute virus infections are important in this respect,

but the mechanism by which such infections kill is still a matter of speculation (Emery, 1968), so we are forced to conclude that external obstruction to respiration could be a contributory factor in some cases.

It must be stressed, however, that the respiratory resistance (as measured by pressure changes) in some cases rose thirty-fold to fortyfold. The length of time a child could sustain effort against such large increases depends on many factors, among which would be coincidental disease and debility.

In testing several infants with the same appliances we obtained different quantitative results, though the qualitative responses remained the same.

Such variations were undoubtedly due to differences in facial contour of the children. It is quite obvious that the flat-faced, snub-nosed type of child is more prone to obstruction when it lies face down than the child with a narrow face and prominent nose. It would therefore seem necessary in future to take particular note of the facial characteristics of children found face down or in a posture from which a possibility of suffocation occurs.

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Appendix. Description of Pillows Studied

"Hospital Pillow"

The hospital pillow examined was of large adult size, approximately twice the length of a child and having a firm consistency and a tense plastic cover. It was covered by a linen pillowcase. It is essentially of the same consistency and firmness as a hospital mattress.

Commercial Pillows

(1) This pillow measures 39 by 29 by 4 cm., is moderately firm, and is covered with a non-detachable linen ticking. It consists of a pad of foam rubber.

(2) This pillow is small, rounded, conventionally shaped, and measures 34 by 25 by 10 cm. The whole is covered by a non-detachable linen ticking, and the pillow consists of small pieces of foam rubber enclosed in a foam-rubber bag having walls

approximately 5 mm. thick. It is soft and has a texture not unlike that of an ordinary feather pillow.

(3) This is a small soft pillow measuring 36 by 26 by 10 cm., and is covered by a non-detachable linen ticking. It is simply filled with a large number of small foam-rubber fragments within a thin foam-rubber envelope.

(4) This is a firm pillow measuring 40 by 24 cm., and having a thickness varying from 7 to 9 cm. It consists of a layer of foam rubber surrounding a closely coiled roll of firm plastic material on one side, and a small, loose, fibrous cushion. The whole is covered by a loosely woven nylon ticking, non-detachable. The foam-rubber surface is perforated by small holes approximately 3 mm. in diameter at intervals of 4.5 cm. This pillow is firm (not rigid) on one side only.

(5) This pillow measures 40 by 26 cm., and varies in thickness from 2 to 4 cm. It consists of a loosely woven nylon ticking enclosing firm, thin nylon wadding. After testing, this wadding broke up into irregular bundles, so that in some areas the pillow as such was virtually non-existent.

(6) Superficially this looks like a conventional small pillow and measures 37 to 28 by 5 cm. It is covered by ordinary white, non-detachable linen ticking, and consists of a moulded mass of foam rubber. This pillow is only moderately firm.

(7) This pillow is exactly the same size as 6, and has the same internal structure as the previous one, but is covered by a loosely woven cotton mesh.

(8) This pillow has been received and tested, but cannot be described, as we cannot now trace it.

(9) This pillow measures 38 by 25 cm., and is approximately 4 cm. thick. It consists of a thinly woven nylon case (non-detachable) filled with a mass of coiled plastic threads having the consistency of rather soft horsehair. This pillow is light, is relatively soft, and light can be seen through it. If it is held underneath a tap water runs straight through it.

(10) This "pillow" is essentially a mattress measuring 73 by 35 by 4 cm. It is made of a single thick mass of foam rubber of the same dimensions, covered by a plastic sheeting, and on the surface, near one end of this, is inserted a linen "window" measuring 28 by 20 cm. This is in the area where the child's head is presumably intended to lie. This "window" consists of fairly closely woven linen, and the mattress is of a fairly firm consistency.

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