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Forensic Engineering Evaluation of CO_2 Re-Breathing in Infant Bedding Materials

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Abstract

A four-month-old infant suffocated in his sleep from positional asphyxia. The baby was found face-down on a foam wedge pillow called a sleep positioner. The author was engaged to evaluate the sleep positioner product for its potential to cause carbon dioxide (CO_2) re-breathing in infants. Prior research on this subject had already established a reliable method of simulating infant breathing and measurement of respiratory gas constituents using a mechanical breathing model.

Guided by this research, a mechanical breathing model and gas sampling apparatus was coupled to a mannequin representing the child in this matter. The mannequin was placed in face-down and side-facing positions on the sleep positioner product and twelve other surfaces, including a plain cotton sheet as the baseline. The sleep positioner product produced the highest (and most dangerous) level of CO_2 re-breathing, more than three times the baseline level. Factors contributing to CO_2 re-breathing are discussed.

Keywords

Carbon Dioxide, Re-breathing, SIDS, Sudden Infant Death Syndrome

Background

Sudden infant death syndrome (SIDS) is the unexpected, sudden death of a child under one year of age in which an autopsy does not show an explainable cause of death. The causes of SIDS are not yet fully understood. Researchers believe that SIDS is caused by several different factors. These factors may include problems with sleep arousal or an inability to sense a build-up of excessive carbon dioxide in the blood.

In the case under discussion, an infant was put to bed on his side on a foam wedge sleep positioner. In the morning, the child was found face-down on the sleep positioner and was not breathing. This author was engaged by counsel for the child's mother to evaluate the sleep positioner product for its potential to create a respiratory hazard. The testing described below was done according to the method used by Carleton.

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During the early 1990's, the U.S. Consumer Product Safety Commission (CPSC) became concerned about reports of infant deaths from suffocation, and conducted studies to determine what kinds of bedding materials may have an adverse effect. While working at CPSC, J.N. Carleton performed studies using a mechanical breathing model to evaluate various bedding materials and infant cushions with regard to re-breathing of carbon dioxide. (1,2)

Test method

As shown in Figure 1, a mechanical breathing device is used to simulate the respiratory volume and frequency typical of the infant under study. Carbon dioxide is introduced into the lung to simulate the infant's rate of metabolism. The model simulates a level of 5 percent CO_2 in the infant airway, under free-breathing conditions. If the infant or model re-breathes its own exhaled CO_2, the concentration in the lung becomes elevated. Carleton, Donahue and Porter used this method to evaluate infant bedding materials in the early 1990's.

Testing

A mannequin (toy doll) was obtained matching the approximate size of the infant at the time of his death. The mannequin's head was weighted internally to simulate the infant's estimated head weight.

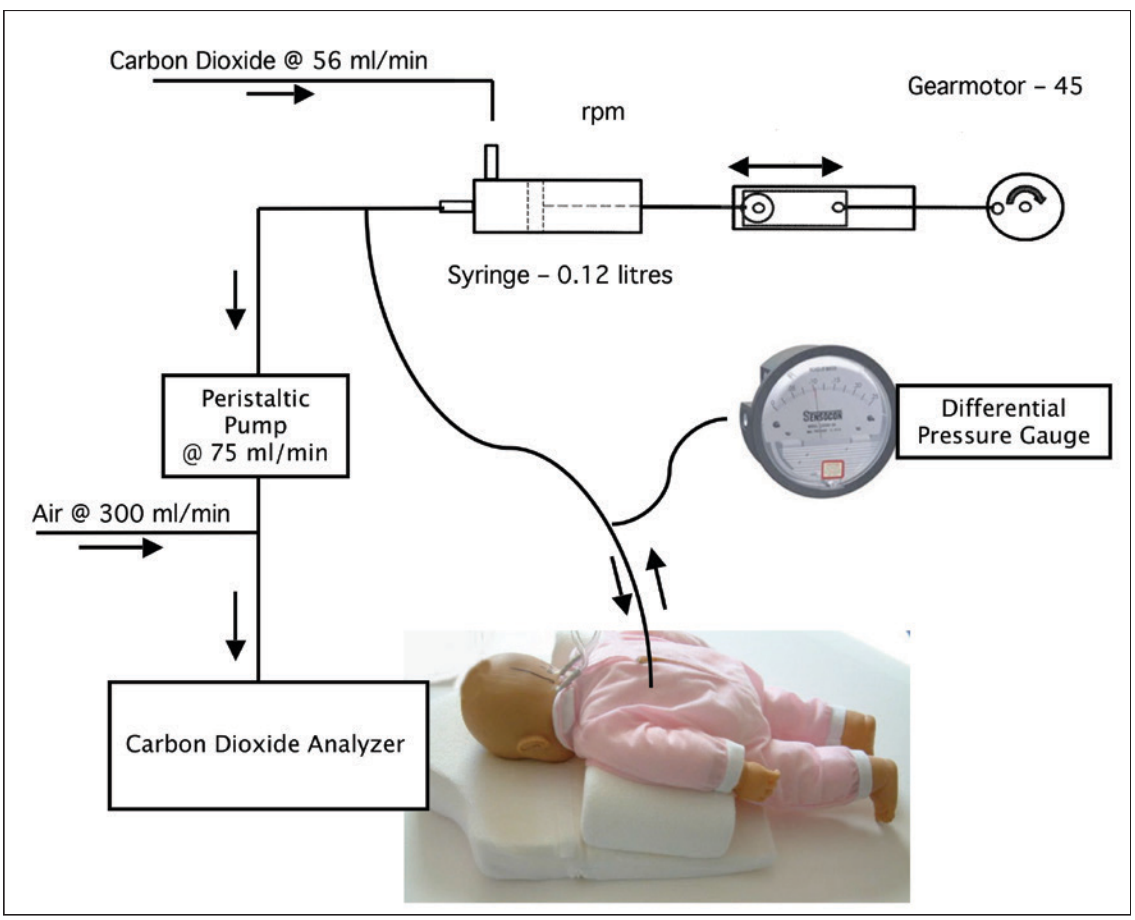

Figure 1

In order to simulate the conditions preceding death, the mannequin was provided with internal heating and temperature control. The head and torso were fitted with 15-watt lamps to provide heat sources, and controlled using temperature sensors located at the mouth and chest. The mannequin was heated to a temperature of 100°F.

A mechanical "lung" was used to simulate natural breathing at a frequency of 45 per minute and volume cycling between 65 and 100 ml. Carbon dioxide was introduced into the lung at a rate simulating normal respiration. An airway was connected between the lung and the mannequin's nose to allow breathing to occur through the nose only. A pump was used to draw a small sample at 75 ml/min. from the airway in order to measure the concentration of CO_2 retained inside the respiratory system. The sample was diluted with air at a 4:1 ratio to provide a sample flow large enough to be measured by a standard laboratory gas analyzer.

The gas analyzer was a Horiba model VIA-510, used in the 5% and 10% ranges. CO_2 at 100% concentration was fed to the mechanical lung at 56 ml./min. Dilution air for the sample was fed at 300 ml./min. The analyzer was calibrated before and after testing using certified grade calibration gas at 4.999% carbon dioxide concentration.

The test setup was designed to duplicate the method used by Carleton, Donoghue and Porter in their 1998 paper entitled "Mechanical model testing of rebreathing potential in infant bedding materials." The lung was actuated using a gearmotor and rotating crank, and a pressure gauge was added to the airway to observe fluctuations as the "baby" breathed. Small fluctuations in pressure indicated free breathing. When the positive and negative pressure excursions grew larger, a breathing restriction was indicated.

Tests were conducted with the mannequin in side-facing and face-down positions on six different surfaces:

- Plastic-covered foam mattress and cotton sheet, with and without blanket over sheet;
- Foam Sleep positioner (closed cell foam facing up), with and without blanket over sleep positioner;
- Foam Sleep positioner (open cell foam facing up), with and without blanket over sleep positioner.

In tests where a blanket was used (shown below), the blanket was a thin receiving blanket. *(A lightweight blanket used to wrap a baby especially after a bath.)* For each test configuration, the carbon dioxide measurement was allowed to stabilize for several minutes before it was recorded. Some of the test configurations are shown below.

Figure 2
Free breathing baseline on mattress and cotton sheet – mannequin on its side

Figure 3
Mannequin face-down on mattress with cotton sheet

Figure 4
Mannequin face-down on mattress with cotton sheet and blanket

Figure 5
Mannequin face-down on foam sleep positioner

Summary of results

Twelve test conditions were evaluated to determine the influence of the sleep positioner product on CO_2 re-breathing:

1. Side-facing on plain mattress and sheet
2. Side-facing on plain mattress and sheet with blanket
3. Side-facing on sleep positioner
4. Side-facing on sleep positioner with blanket on sleep positioner
5. Side-facing on bottom of sleep positioner
6. Side-facing on bottom of sleep positioner with blanket on sleep positioner
7. Face-down on plain mattress and sheet
8. Face-down on plain mattress and sheet with blanket
9. Face-down on sleep positioner
10. Face-down on sleep positioner with blanket on sleep positioner
11. Face-down on bottom of sleep positioner
12. Face-down on bottom of sleep positioner with blanket on sleep positioner

Results are shown below.

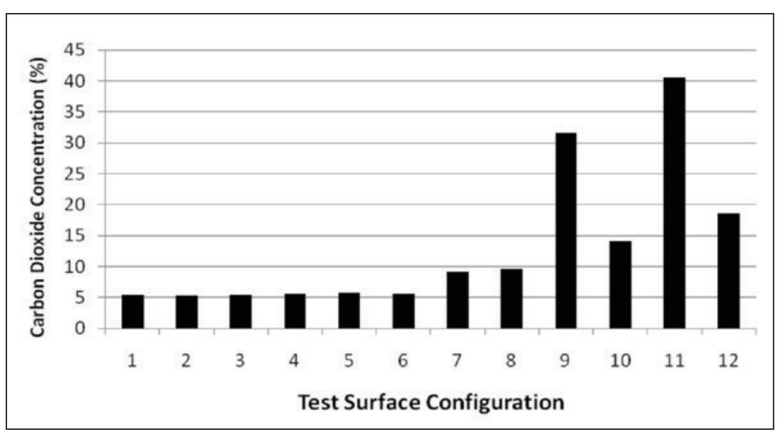

Figure 6

Figure 7
Quilt

Figure 8
Bean Bag Pillow

Figure 9
Wool Blanket

Figure 10
Lamb's Wool

Figure 11
Pillow

Figure 12
Cotton Towel

Figure 13
Fleece

Figure 14
Sleeping Bag

Summary of results – Second test series

A second test series was performed using eight reference sleep surfaces. The reference surfaces were:

13. Face-down on quilt
14. Face-down on bean bag cushion
15. Face-down on wool blanket
16. Face-down on Lamb's wool
17. Face-down on pillow
18. Face-down on cotton towel
19. Face-down on fleece
20. Face-down on down sleeping bag

These reference surfaces were evaluated to provide a comparison to surfaces that have been evaluated by other researchers, and to provide a frame of reference for the effects of the sleep positioner. The baseline level of about 5% CO_2 concentration represents free breathing, as measured in the side-facing configurations.

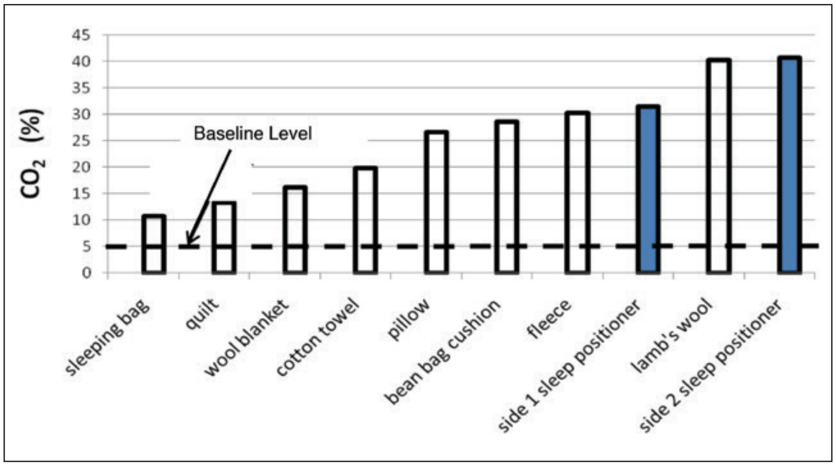

Figure 15
Reference materials compared to sleep positioner

Analysis

The sleep positioner is made from two layers of soft foam material with a cloth cover. The bottom layer is made from open-cell foam that is permeable, and the top layer of the cushion is made from closed-cell "memory foam", which is impermeable. The foam has a removable cotton cover. Two cylindrical foam bolsters are attached to the cover using Velcro.

When a child is face-down, the foam tends to conform to the shape of the child's face, forming a "bowl" under and around the child's face and promoting re-breathing of expired respiratory gases. CO_2 -laden exhaled air is heavier than room air, and the "bowl" contributes to retention of the CO_2. When the sleep surface is permeable with a high fraction of air spaces within to act as a reservoir, the re-breathing effect appears to be more acute. A quiescent sleep environment with little air movement around the child would seem to aggravate the effect as well.

Figure 16
Mannequin face-down on bare memory foam

This re-breathing effect results in an increase in the concentration of retained carbon dioxide in the respiratory system. The memory foam surface is illustrated below, showing the sleep positioner with the cloth cover removed to illustrate the "bowl" effect.

Figure 17
The memory foam molds to the baby's face

When an infant is face-down, the type of sleep surface has a profound effect on re-breathing of carbon dioxide. Previous studies at CPSC have confirmed this effect and led to the recall and banning of certain types of cushions for use with infants. The most dangerous of the banned sleep surfaces are those that form a pocket around the infant's face, such as sheepskins and bean-bag pillows.

In these test series, the sleep surface producing the highest concentration of carbon dioxide re-breathing was the sleep positioner. The porous foam (lower) surface of the sleep positioner produced even higher CO_2 concentrations than the top surface. When a standard receiving blanket was interposed between the infant and sleep surface, the blanket caused a significant reduction in carbon dioxide re-breathing in all face-down tests.

Conclusions

1. The subject sleep positioner causes very high levels of carbon dioxide re-breathing when the infant is face-down on the product;
2. The effect of this sleep positioner on infant re-breathing is similar to the effect of those pillows and cushions which had already been recalled and banned by Federal law;
3. The observed effects using a test mannequin would be expected to have similar effects on a living infant, and;
4. If an infant is face-down on a foam sleep positioner of this design and construction, breathing is likely to be severely compromised.

Note – On September 29, 2010, the U.S. Consumer Product Safety Commission and FDA warned consumers to stop using infant sleep positioners. Following the warnings from CPSC and FDA, the lawsuit settled favorably for the Plaintiff.

References

1. Mechanical model testing of rebreathing potential in infant bedding materials, Carleton JN, Donoghue AM, Porter WK., Arch Dis Child. 1998 Apr;78(4):323-8.
2. When a link was established between Sudden Infant Death Syndrome and sleep surfaces, the Federal government banned certain types of infant cushions and pillows in 1992. (1994 Annual Report to Congress, U.S. Consumer Product Safety Commission)