

CASE REPORT

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The Role of Environmental Factors in the Causation of Sudden Death in Infants: Two Cases of Sudden Unexpected Death in Two Unrelated Infants Who Were Cared for by the Same Babysitter

ABSTRACT: We report two cases of sudden unexpected death in two unrelated African American female infants, 2 months and 4 months old. Both infants were attended to by the same babysitter in the same apartment and died 39 days apart in the same bed and in the same bedroom. The autopsy of the first infant revealed sudden unexplained death in an infant. Toxicologic analysis for carbon monoxide (CO) was not performed because it was not suspected. When the second infant died, investigation into the ambient air quality within the apartment revealed high levels of CO emanating from a poorly ventilated and defective hot water heater, which was located across a hallway from the bedroom where the two babies died. CO saturation levels in the postmortem blood samples of the two babies were elevated and were similar (13% and 14%). Nicotine and cotinine were not detected in the blood sample of the two infants. Cherry-red livor mortis was absent. Acute CO intoxication was determined to be the underlying cause of these two unexpected deaths. These two cases underscore the need to integrate ambient air analysis and postmortem CO analysis as routine components of the comprehensive death investigation of infants who die suddenly and unexpectedly.

KEYWORDS: forensic science, carbon monoxide, sudden unexpected death

Simultaneous or repeated sudden, unexpected, and even unexplained, deaths, have been known to occur in twins, siblings, related, and unrelated infants in the same household or under the care of the same caregiver/babysitter within a common environment (1–9). Many of these deaths have been suspected to be due to natural or unnatural causes including adult-induced nonaccidental trauma, sudden infant death syndrome and genetic diseases. The pertinent characteristic in many of these cases is the occurrence of unexpected death in apparently healthy infants within the same environment. When these forensic circumstances occur, a critical issue, which may arise in the investigation of these deaths is whether there may be an incriminating causal environmental factor, which may account for these sudden unexpected deaths. We report two cases of sudden unexpected deaths in the same environment of two apparently healthy African American infants from unrelated parents and families. These infants died 39 days apart in the same bed and in the same bedroom while under the care of the same babysitter. Ambient air quality analysis of the apartment, after the second death, revealed high carbon monoxide (CO) levels emanating from a poorly ventilated and defective water heater in the laundry room, which was directly across the hallway from the bedroom

where the babies died. Toxicologic analyses of postmortem blood samples revealed elevated blood CO saturation levels, which were similar (13% and 14%) in the two infants. Nicotine and cotinine (nicotine metabolite) were not detected in the blood samples of the two infants. Cherry-red livor mortis, which is an expected finding in CO intoxication, was not observed in the two cases. The absence of cherry-red livor mortis in fatal CO intoxication has been reported in the literature (10,11). Moreover, levels of CO blood saturation below 20% do not usually produce a cherry-red discoloration (12). Fetuses, neonates, and young infants are more vulnerable to CO exposure than adults due to higher CO-affinity of fetal hemoglobin and the higher basal metabolic rates (13–15) in early neonates and early infants. Without the second death, and without an ambient air quality analysis, acute CO intoxication may neither have been suspected nor identified in these two cases. These two cases underscore the vital role routine, ambient air quality analysis and routine blood CO analysis may play in the investigation of deaths in infants, and in the accurate diagnosis of causes of sudden and unexpected deaths in infants.

Case Reports

Case One

The first infant was a 2-month-old African American female who died on February 15 on a cold winter day in a two bedroom apartment, which was located in an inner city neighborhood. She had been brought to the apartment by her mother around 9:00 P.M. and was being cared for by a 55-year-old baby-sitter, who was not known to be a member of the infant's extended family. This was

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the first over-night stay of the infant in the baby-sitter's apartment. She was fed around 11:00 P.M. and was placed lying face down in the middle of a full-sized adult bed, which was located in a bedroom that was across a hallway from a utility closet. The bed was covered with a fitted bed-sheet and contained a blanket but no pillows. This utility closet contained a natural gas-powered hydro heat system, an electric washing machine and an electric dryer. During the entire day and night of the infant's death, and while the infant was in the apartment, the babysitter used the washing machine and dryer performing a whole week's laundry for her household. She washed and dried multiple loads of clothing. Also sleeping in the second bedroom at the same time was the decedent's 9-month-old brother. The second room was located down the hallway further away from the utility room and water boiler. The baby-sitter was in the apartment performing laundry and playing a game in the kitchen area with her 13-year-old son until approximately 3:00 A.M. The babysitter checked on the infant in bed around this time and found her unresponsive. The baby was emergently transported to a local hospital where she was pronounced dead. The deceased baby had been seen at the same local hospital 1 week prior for cold symptoms.

Scene investigation revealed a two bed-room city apartment with poor aeration, all windows and doors remained constantly closed. Aerosolized air fresheners were present in each room. Smoke detectors were installed inside the apartment. CO detectors were not installed inside the apartment. Numerous children's toys and piles of clothing were scattered through out the apartment especially in the living room area. A playpen, a child's seat and a baby gym were also present in the living room.

The father and mother of the deceased child were 24 and 19 years old respectively and were not married. The deceased child was born at 36 weeks gestation per vaginam, measured 18 inches and weighed 6 pounds 11 ounces. Pregnancy was uneventful. Prenatal care was begun at 12 weeks gestation and the mother smoked cigarettes during the pregnancy. The baby was not breast fed.

A complete autopsy with comprehensive neuropathologic examination revealed an anatomically normal infant. The baby appeared adequately developed and well nourished for age, weighed 4800 g and measured 56 cm crown-to-heel length and 37 cm head-circumference. Plain full-body X-ray revealed no skeletal fractures. There was no evidence of trauma. All internal viscerae were unremarkable except for visceral parenchymal congestion including pulmonary and cerebral edema and congestion. Routine toxicologic analyses of the blood revealed no drugs. No CO blood saturation analysis was performed at this time. Bacterial and viral cultures of the blood, heart and lungs were negative. Electrospray ionization-tandem mass spectrometry and screening of the blood and bile revealed normal acylcarnitine profiles and no biochemical evidence of any underlying fatty acid transport and mitochondrial oxidation disorder. The preliminary and tentative cause of death was sudden unexplained death in an infant.

Case Two

The second infant was a 4-month-old African American female who died on March 26 on a cool spring-like day in the same two bedroom apartment, where the first infant had died 39 days earlier. This second infant did not have any known direct familial link with the first infant. They came from different parents and families. However, the second infant was the paternal grandchild of the same babysitter who had cared for the first infant. This was the first over-night stay for the infant in this apartment. During the entire day and night of the infant's death, and while the infant was

in the apartment, the babysitter used the washing machine and dryer performing a whole week's laundry for her household. She washed and dried multiple loads of clothing. On the day of the infant's death, she was sleeping on one side of the same full-sized adult bed with her grandmother/babysitter in the same bed and in the same bedroom where the first infant had died. The grandmother had placed several pillows between her and the infant to prevent any possibility of an over-lay. She fed the infant at approximately 6:30 A.M. and placed her back in bed lying prone with her head turned sideways. Also present at the apartment at this time were the babysitter's 13-year-old son and her 9-month-old grandson.

The babysitter/grandmother woke up at 9:30 A.M. and found the infant unresponsive. 911 was called and the infant was emergently taken to a local hospital. Cardio-respiratory resuscitation was unsuccessful and the infant was certified dead. The case was initially investigated by the local police department as a possible homicide due to the recurrence of sudden death in an infant in the same apartment in less than 40 days. Scene investigation revealed findings, which were similar to the findings at the scene following the death of the first infant.

The mother of the deceased second infant was 24 years old. Her two previous babies had died in the neonatal period. The first male neonate died 5 years prior. He was born at 23 weeks gestational age and died 1 h after birth. The cause of death was prematurity. The second male neonate died 1 year prior. He was born at 28 weeks gestational age and died 1 week after birth from prematurity. The father of this deceased child was 25 years old and was incarcerated approximately 2 weeks prior to the infant's death. Both parents were not married. The deceased child was born at 36 weeks gestational age by cesarean section, weighed 5 pounds 4 ounces and measured 18 inches. Pregnancy was uneventful and the mother smoked during pregnancy. She had an AS hemoglobin genotype and was diagnosed with gastro-esophageal reflux disease. Two days prior to death the infant received routine immunization shots at 4 months. She was not breastfed.

A complete autopsy with comprehensive neuropathologic examination revealed an anatomically normal infant. The baby appeared adequately developed and well nourished for age, weighed 6800 g and measured 61 cm crown-to-heel length and 37 cm head-circumference. A plain full-body X-ray did not reveal any skeletal fractures. There was no evidence of trauma or an over-lay. All internal viscerae were unremarkable except for visceral parenchymal congestion including pulmonary and cerebral edema and congestion. Examination of the eyeballs did not reveal any retinal hemorrhages or evidence of ocular trauma. Routine toxicologic analyses of the blood revealed no drugs. Bacterial and viral cultures of the blood, heart, and lungs were negative. Electrospray ionization-tandem mass spectrometry and screening of the blood and bile revealed normal acylcarnitine profiles and no biochemical evidence of any fatty acid transport and mitochondrial oxidation disorder.

Ambient Air Quality Investigation

Due to the temporal proximity of these two deaths in the same apartment, the local public health department was requested to perform an ambient air analysis within the apartment. An environmental health specialist conducted an indoor air quality evaluation 3 days after the death of the second infant, after the windows and doors in the apartment had been opened and the apartment aerated. The air quality evaluation comprised air testing, air sampling, walk through evaluation of the premises, and evaluation of the heating and cooling systems. Upon entry into the apartment there was an odor of byproducts of gas combustion. Space heating and hot water

were provided by a 50 gallon, 50,000 BTU hydro heat hot surface ignition, power vent gas water heater. Cooling was provided by conventional air conditioning. The hydro heat system and an electric washing machine and dryer were located in a utility closet, which was across the hallway from the bedroom the two infants died in. The closet measured approximately 4 feet 8 inches \times 6 feet 9 inches \times 7 feet, total volume was approximately 217.35 cubic feet.

Combustion air was provided by an approximately 21 \times 10 inch 194.75 square inch louvered grill, which was located near the floor on the left side of the wall. The effective open area was approximately 136.35 square inches. Per the National Fuel Gas Code, equipment located inside a building in a confined space shall be provided with two permanent openings communicating directly with an additional room. Each opening shall have a minimum free area of 1 square inch per 1,000 BTU/h, but not less than 100 square inches. One opening shall be within 12 inches of the top of the enclosure, the other within 12 inches of the bottom. The combustion air opening was partially blocked by clothing on the floor and clothing hanging on the wall above the combustion air inlet. The lint filter was missing on the electric dryer and there was a kink in the exhaust hose that may have accumulated lint.

Analysis of ambient air quality inside the apartment revealed allowed/normal levels of carbon dioxide (475–500 ppm), temperature (72–74°F), humidity (32–38%), particulates (27 47 mcg/m³), CO (0 ppm), hydrogen sulfide (0 ppm), volatile organics (0.005 ppm), mold (35–47 CFU), total hydrocarbons (0.005 ppm).

Evaluation and testing of the hydro heat hot water heater revealed that it was producing CO at a level of 40 ppm at the vent connection. The unit was red-tagged for CO production and insufficient combustion air. The CO level of the ambient air was 0 ppm. This was expected as the ambient air analysis was performed 3 days after the death of the second infant and after the doors and windows in the apartment had been opened and the apartment aerated.

The management company of the apartment complex was in part cited for the following violations: back-drafting gas water heater, CO hazard and inadequate make-up air for gas water heater operation. The management company was advised to determine the cause of the back-drafting and repair it; check vent pipes to exclude blockage, provide adequate make-up air, contact gas company for proper requirements for make-up air and additional louvers in folding doors may be needed. The apartment was vacated and the babysitter was moved to a separate residence.

Blood Carbon-Monoxide Saturation Analysis

Following the ambient air analyses, postmortem blood samples of the two infants were submitted to a specialized toxicology laboratory for blood CO saturation, nicotine, and cotinine (nicotine metabolite) analyses. Spectrophotometry analysis of the blood revealed carboxyhemoglobin levels of 13% and 14%, respectively in the first and second infants. Gas chromatography and mass spectrometry analysis of the postmortem blood samples from the first and second infants did not detect the presence of nicotine or cotinine in both infants.

The cause of death of both infants was determined to be acute CO toxicity and the manner of death was determined to be accidental.

The babysitter and her family members were immediately relocated to another apartment after the death of the second infant. Their blood CO saturation levels, which were determined by a

local clinic approximately 2 months after the death of the second infant were all less than 5%.

Discussion

Carbon monoxide is a colorless, odorless, and tasteless gas and humans do not have the innate capacity to detect its presence in the environment. The mechanism of human toxicity of CO involves cellular asphyxiation. CO has about 250 times binding affinity for hemoglobin than oxygen and displaces oxygen to form carboxyhemoglobin (COHb) in the blood. CO also binds to the mitochondrial enzyme, cytochrome oxidase (complex III—succinate-coenzyme Q reductase, and complex IV—cytochrome c oxidase), to inhibit the production of Adenosine Triphosphate (ATP). Cells are deprived of oxygen and ATP resulting in cellular metabolic failure, mitochondrial failure, and eventual death (16).

Forensic pathologists may not rely upon a cherry-red livor mortis for the suspicion of fatal CO intoxication especially in infants. As has been illustrated by our two cases, cherry-red livor mortis may be absent when CO saturation levels are lower than 20% (12). CO saturation levels as low as 20–30% may be fatal in adults especially when there is a pre-existing decompensation in cardio-respiratory reserve (2,12,17). Even lower CO saturation levels may be fatal in fetuses and infants (18) as fetal hemoglobin has a greater affinity for CO than adult hemoglobin (19). The fetal hemoglobin dissociation curve lies to the left of the adult curve, resulting in greater tissue hypoxia at similar carboxyhemoglobin levels (20). Fetal CO intoxication deaths have been reported with low, innocuous, and nonlethal levels of CO poisoning in the mothers (14,15,21). In the report by Farrow et al. (15), the fetal COHb level was 8.7 times the COHb level in the mother. In the report by Omaye S (16) fetal hemoglobin may form COHb levels that are 10–15% higher than adult hemoglobin.

Fetal hemoglobin comprises 50–95% of a neonate's hemoglobin at birth. These levels decline after 6 months as adult hemoglobin synthesis is activated while fetal hemoglobin synthesis is deactivated. It takes about 2 years for a baby to completely switch over to adult hemoglobin.

The adverse effects of CO on mitochondrial functioning further accentuate the vulnerability of early infants to CO toxicity because of the high basal metabolic rate (BMR) in infants. BMR is defined as the minimal rate of energy generation and expenditure, which will sustain life. Infants require basal metabolic rates per unit body size, which are much higher than older children and adults. Highest values of BMR in humans are observed in infants and per unit of body weight the BMR at age 20 is only just over 30% of its value in the first year of life (22).

In our two cases the two infants were 2 and 4 months, respectively, and amongst the other individuals in the apartment, they were the most naïve to CO exposure and the most vulnerable to the toxic effects of CO intoxication even at lower levels.

There was a confirmed source of CO in the apartment: a natural gas heater. Ambient air quality analysis of the apartment revealed that the utility closet where the heater was located was not adequately ventilated and the heater was back drafting gas. CO levels within the apartment remained un-monitored given the absence of CO detectors and possibly high CO levels were not detected.

The postmortem interval between the determination of blood COHb saturation in our two cases is not forensically significant. Blood COHb saturation is not affected by postmortem changes. The interpretation of levels of blood COHb saturation should not be affected by postmortem interval or postmortem formation of CO (23–25).

Ramos et al. (20) have reported CO-induced simultaneous sudden deaths in identical male twin infants at the age of 45 days old with COHb saturation levels of 10.3%, which is similar to the COHb levels in our two cases (13% and 14%). In the two cases reported by Ramos et al. the parents and other siblings in the household remained unharmed by CO. This further suggests that low blood COHb saturation levels, which may be nonfatal in adults and older children, may be fatal in infants.

Multiple studies have associated increased environmental levels of nitrogen dioxide (NO₂) and CO with increased numbers of sudden deaths in infants (26–29). Our two cases show that ambient air quality analysis of the immediate environment and CO analysis of postmortem blood should become routine components of the death investigations of infants who die suddenly and unexpectedly. The air quality analysis will possibly identify any source of noxious gases like CO and possibly avoid any future deaths in the household. At autopsy the absence of a cherry-red or red-pink livor mortis should not preclude blood CO saturation analysis.

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