Forensic pediatric radiology: studies in living and deceased children

Hoogendoorn, T.

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Chapter 13

Pneumomediastinum and soft tissue emphysema in pediatric hanging

T. Sieswerda-Hoogendoorn\textsuperscript{a,b}
A.S. Strik\textsuperscript{c}
N.F.J. Hilgersom\textsuperscript{c}
V. Soerdjbalie-Maikoe\textsuperscript{a}
R.R. van Rijn\textsuperscript{a,b}

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\textsuperscript{a} Section of Forensic Pediatrics, Department of Forensic Medicine, Netherlands Forensic Institute, the Hague, the Netherlands; \textsuperscript{b} Department of Radiology, Academic Medical Center/Emma Children’s Hospital, Amsterdam, the Netherlands; \textsuperscript{c} Faculty of Medicine, Academic Medical Centre, University of Amsterdam, the Netherlands.
ABSTRACT
Postmortem computed tomography (CT) is increasingly being used as a tool in forensic pathology. The exact value of postmortem imaging in detecting specific conditions has not yet been established, but in specific cases, it can be used as a diagnostic tool demonstrating findings that remain undetected during autopsy, as in this case. Pneumomediastinum and soft tissue emphysema were detected with postmortem CT in a 3-year-old girl after hanging. It was not found during autopsy. This radiological finding matches three adult cases previously described. It is assumed that in this case, the first reported in a child, hanging was the most likely cause as well. In the adult cases, it was interpreted as a vital sign; the person must have been alive to create a pressure gradient causing rupture of the alveoli. This case demonstrates one of the added values of postmortem imaging, the possibility of demonstrating findings that remain undetected during autopsy.
INTRODUCTION
Postmortem imaging, as an addition to the conventional judicial autopsy, is increasingly being used as a tool in forensic pathology. The advantages of postmortem radiological imaging are that it is a noninvasive modality and yields a result that can be kept and shared unaltered over time. This makes it possible to reassess the data in future if needed, in contrast to an autopsy in which the quality of reassessment will decline in time because of postmortem changes. In recent years, numerous publications on the use of postmortem imaging, especially computed tomography (CT), have appeared in radiological as well as forensic journals. Based on their research, Bolliger et al. conclude that the use of CT has proven “to be an invaluable tool in three areas of forensic pathology, namely in the detection and demonstration of fractures, the detection of foreign bodies, and the detection of gas”.¹ The first validation study on postmortem imaging in adults revealed a major discrepancy rate between imaging and autopsy in establishing the cause of death of 30%.² The exact value of postmortem imaging in detecting specific conditions has not yet been established, and no reliable positive and negative predictive values for different conditions have been determined. It is known, however, that on a case by case basis, it can be used as a diagnostic tool demonstrating findings that remain undetected during autopsy, as is demonstrated in this case. A child in which postmortem imaging demonstrates the presence of pneumomediastinum and soft tissue emphysema is presented. These findings are interpreted as a result of compression of the neck by hanging.

CASE
A 3-year-old girl was found by a neighboring child hanging in the stairwell at home. The child alarmed his parents who called the general practitioner (GP). The GP found the girl with a rope around her neck in full suspension, cut the rope, and called emergency services. Although the body was already cold when they arrived, resuscitation was started. Resuscitation was stopped according to protocol when no signs of life were detected. The girl was previously in good health. Because of privacy considerations, no details about the family can be presented. The mother and siblings were at home when the girl was found. One of the siblings, walking around in the house, had a piece of rope tied around his neck. Two pieces of rope were hanging in the stairwell, one was cut (by the GP), and one was tied in a slip knot. More rope was found elsewhere in the house. The knots in the ropes could not have been tied by a young child. The mother was mentally confused at the moment the GP and emergency services arrived and not able to clarify what happened. She was arrested, and in the police interrogations during the investigations, it became clear that she intended to kill her four children and subsequently commit suicide. The sibling with the rope around his neck had also briefly been hung by the mother, but she untied him when the doorbell rang. According to the mother, the children were alive when she hung them. The mother was diagnosed with a psychiatric disorder by two forensic psychiatrists and was convicted to imprisonment and subsequent detention in hospital.
Radiological Findings
As part of the standard protocol of the Netherlands Forensic Institute, a skeletal survey and postmortem total body CT were performed before forensic autopsy. The scan was performed several hours after death on a Philips Brilliance 64-slice CT scanner (Philips Medical Systems, Best, the Netherlands). Scan parameters were as follows: 210 mAs, 300 kV, and slice thickness 0.9 mm, and coronal and sagittal reconstructions were obtained. The radiological studies were evaluated by a board-licensed pediatric radiologist without prior knowledge of the autopsy findings. Skeletal survey showed no abnormalities, especially no rib fractures. Computed tomography revealed extensive cervical and thoracic soft tissue emphysema and a pneumomediastinum (Figs 1 and 2a-c). No fractures, especially no fractures of the cervical spine or hyoid bone, were detected on CT imaging. It should be noted that only dislocated fractures of the hyoid can be seen on CT. Advanced visualization, adapted from Aghayev et al., consisted of 3-D rendering of gas structures (Fig. 3).

Autopsy Findings
An autopsy was performed according to the pediatric forensic autopsy protocol by the Netherlands Forensic Institute. During autopsy, a full circular hanging mark around the neck was detected, with a constant width of five millimeter, with redness on the edges due to subcutaneous bleeding. There were no abrasions and no bruises. The mark was situated higher just under the left ear, where a vague point of suspension was observed (Fig. 4). Petechial hemorrhages were observed in the eyelids, facial skin, and conjunctivae (Fig. 5).

Figure 1. Coronal reconstruction displaying the axial levels as shown in Figure 2a–c.

Figure 2a. Axial computed tomography (CT) scan in lung setting. This shows subcutaneous emphysema (solid arrow), air in the trachea (open arrow) with air in the adjacent esophagus, and air surrounding the left common carotid artery (solid arrowhead) and left jugular vein (open arrowhead). Figure 2b. Axial CT scan in lung setting. This shows subcutaneous emphysema (solid arrow), pneumomediastinum (open arrow), and air surrounding the left common carotid artery (solid arrowhead) and left subclavian artery (open arrowhead). Figure 2c. Axial CT scan in lung setting. This shows pneumomediastinum (open arrow), air fluid level in the esophagus (solid arrowhead), and postmortem consolidation of lung parenchyma (open arrowhead).
internally on the surface of the heart. At autopsy, no subcutaneous or mediastinal emphysema was observed. It should be noted that palpation of the body is not a standard procedure during autopsy. If this had been performed, the emphysema probably would have been detected. The pneumothorax was not diagnosed. There were no injuries internally in the neck (no hemorrhages, no fractures of the hyoid and laryngeal structures). There were no hemorrhages at the attachment points of the anterior neck muscles. Trachea and oral cavity were intact; both showed no signs of a traumatic intubation. Organ weights of the brain and lungs were higher than normal as a sign of edema, which was confirmed later microscopically. There were no signs of disease macroscopically and microscopically. Toxicology investigation demonstrated no alcohol or drugs. A small amount of atropine was detected, which was given during resuscitation. Cause of death was explained by cerebral ischemia due to carotid occlusion and/or airway occlusion by direct compression of the larynx or trachea. Injury of the neck showed subcutaneous bleeding, indicating that this injury was caused, while the victim was alive. Whether there had been other forms of violence, for example, airway obstruction caused by compression of the nose and mouth or other forms of violence on the neck, cannot be excluded based on autopsy results. A possible contribution to the cause of death by a cardioinhibitory reflex cardiac arrest cannot be excluded.

Figure 3. 3-D reconstruction of gas collections shows a pneumomediastinum and extensive emphysema of the thorax and the neck.

Figure 4. Circular hanging mark with abrasions, impression, and hemorrhage in the edges.

Figure 5. Petechial hemorrhages in the eyelids, facial skin, and conjunctivae.
DISCUSSION

Findings of soft tissue emphysema and pneumomediastinum after hanging, as reported in this case, have previously been described by Aghayev et al.\(^6\) in an adult population. They described the presence of pneumomediastinum and soft tissue emphysema of the neck in three of five adults who died as a result of hanging. This is the first pediatric case in the literature. Pediatric hanging is extremely rare, in contrast to adults where this is a commonly encountered suicide mechanism. Most of the pediatric hanging cases are accidental, while this case illustrates a nonaccidental form, which is exceptional. Accidental hanging in children is mostly related to curtain and blind cords, key cords, and child restrainers, and in children playing “the choking game”\(^6–14\). In older children, autoerotic asphyxiation as an accidental form of hanging and suicide by hanging are, although rare, also encountered.\(^15,16\)

The mechanism of the development of pneumomediastinum was first presented by Macklin and is known as the “Macklin effect”.\(^17,18\) The basic mechanism is explained by the presence of a pressure gradient, between the air-filled alveoli and the surrounding interstitial tissue. This pressure gradient causes alveolar rupture with air leaking into the pericapillary interstitial pulmonary tissue. The interstitial space is connected with the periarterial, peribronchial, and perivenous sheaths. Leakage from these spaces will allow air to enter into the mediastinum, leading to a pneumomediastinum. If the air leaks from the mediastinum, through the fascia it can leak into the cervical and subcutaneous soft tissues. The similarity with the cases described by Aghayev et al. suggests that these radiological findings probably result from the trauma described, hanging. Although putrefaction can cause pneumomediastinum in combination with emphysema as well, in this case the time between death and imaging is too short to explain this finding. The absence of other signs of putrefaction, for example, the absence of intravascular gas on postmortem CT and the absence of alcohol by toxicological investigation, supports this theory. Another mechanism that might cause pneumomediastinum and subcutaneous emphysema is cardiopulmonary resuscitation (CPR). It can be caused by injury of the trachea due to traumatic intubation, rib fractures due to chest compressions causing pneumothorax, or rupture of the alveoli due to high intrathoracic pressure.\(^19–23\) The adult cases described by Aghayev were not resuscitated, as they were found hours after death. The girl described in this case report had been resuscitated, although the forensic report suggests that this started after her demise. The complication rate of CPR is very low. Matshes et al. found one case of emphysema in 383 children who received CPR. Other studies did not find any emphysema or pneumomediastinum in children after CPR\(^25,26\), although in the study by Bush et al., in 1 of 211 children, a pneumothorax was found.\(^25\) There were no signs of traumatic intubation or rib fractures in our case. However, the possibility of rupturing of the alveoli by CPR cannot be excluded. Between 2008 and 2011, 99 pediatric postmortem CTs were performed in our forensic institute. In only two of them, the cause of death was hanging. Only in one of these cases, pneumomediastinum and subcutaneous emphysema were detected. This is in line with the findings by Aghayev et al., who performed postmortem CT in 95 cases. Pneumomediastinum and soft tissue emphysema were only present in three cases, which
all died because of hanging. Therefore, hanging is considered to be a more probable cause of these findings than CPR. Furthermore, the localization of the air in neck and head suggests that it developed while the body was in vertical position. In many forensic cases, the origin of soft tissue emphysema in combination with pneumomediastinum may not be clear, and a differential diagnosis should be considered. Pneumomediastinum in children can be caused by several medical conditions. The most common causes are cited to be asthma exacerbation and pulmonary infection.\textsuperscript{27,28} Spontaneous pneumomediastinum (also known as Hamman’s syndrome) is seen in combination with and without subcutaneous emphysema. It is a well-known phenomenon with a bimodal peak incidence in children below the age of 4 years and children aged 15–18 years.\textsuperscript{29–31} It is caused by alveolar rupture due to a sudden increase in intrathoracic pressure. It can develop after events that trigger a Valsalva maneuver. Other rare causes described in the literature are measles infection\textsuperscript{32–35}, temporomandibular joint surgery\textsuperscript{36}, dental extraction (most likely as a result of the use of air-powered tools)\textsuperscript{37–42}, foreign body aspiration\textsuperscript{43–48}, ketoacidosis in diabetic patients\textsuperscript{49}, and playing wind instruments.\textsuperscript{50} If hanging is the cause of pneumomediastinum and soft tissue emphysema, this can be interpreted as a vital sign, as the person must have been alive to create a pressure gradient. In a forensic setting, this can be important as it demonstrates that the person must have been alive at the time the trauma occurred. In this case, however, vitality of the hanging mark was already confirmed as there was subcutaneous bleeding around the edges, indicating that the victim was alive at the time of the trauma. The preferable imaging tool for the detection of pneumomediastinum and soft tissue emphysema is computed tomography.\textsuperscript{4} The detection of gas within soft tissues is difficult at autopsy, and the findings of pneumomediastinum or soft tissue emphysema are frequently missed\textsuperscript{4}, like in our case. This is the first case in the literature demonstrating cervical and thoracic soft tissue emphysema and a pneumomediastinum in a child after hanging. Although CPR cannot be excluded as a cause of the radiological findings in this case, the resemblance with the cases described in adults suggests a common pathway. Furthermore, this case illustrates the efficacy of postmortem imaging in detecting gas formation, which in some cases is not detected during autopsy.

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