Forensic pediatric radiology: studies in living and deceased children

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Chapter 12

The value of postmortem CT in neonaticide in case of severe decomposition: description of 12 cases

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ABSTRACT
In cases of neonaticide with delayed finding of the body, interpretation of autopsy results can be difficult because of decomposition. Postmortem computed tomography (PMCT) has become an increasingly popular tool in the (pediatric) forensic field. We performed a retrospective study to compare the outcome of PMCT with autopsy results in suspected neonaticide, in neonates found more than one week after their demise. We compared the performance of both methods on (1) determining gestational age, (2) differentiating between live birth and still birth and (3) determining cause of death. We selected all consecutive neonaticide cases with an estimated postmortem interval longer than one week, who underwent a forensic autopsy including a total body PMCT in the Netherlands Forensic Institute in the period 2008-2012. Both a pathologist and radiologist scored gestational age, signs of live birth and cause of death for each case. Twenty-two cases of neonaticide were identified in the study period, of which 15 cases were estimated to be found more than 1 week after death. In 12 of these a total body PMCT was performed. In all cases, late postmortem changes were present. Gestational age could be assessed with PMCT in 100% of the cases and with autopsy in 58% of the cases. In all cases neither PMCT nor autopsy was able to assess live birth and cause of death. PMCT is a better tool for estimating gestational age in case of suspected neonaticide with late postmortem changes compared to autopsy and should therefore be a standard part of the work-up. Signs of live birth and cause of death could not be determined with neither of the methods, an adjusted postmortem examination including limited autopsy for these cases might be developed.
INTRODUCTION
Neonaticide is defined as the killing of an infant within 24 hours after birth. The reported incidence of neonaticide in industrialized countries ranges between 2.4 per 100,000 and 7.0 per 100,000. Neonaticide is the most common form of infanticide; the risk of being a victim is highest on the first day of life. The aim of the forensic autopsy in suspected neonaticide is to address three questions; the first is to assess the gestational age of the child in order to determine whether the child was born at a potentially viable gestational age; the second is to assess whether the child was born alive or was a stillbirth in order to determine the severity of the criminal offense committed and the third is to determine the cause of death. In cases of neonaticide with delayed finding of the body, interpretation of autopsy results can be difficult because of late postmortem findings. Older children are more often found shortly after their demise, while victims of neonaticide tend to be found later, even years after their demise. Severe decomposition limiting the value of the autopsy has been described in 27% of neonaticide cases.

Postmortem computed tomography (PMCT) has become an increasingly popular tool in the (pediatric) forensic field. It is being used to estimate gestational age, as well as to assess live birth and to determine the cause of death. The use of CT in order to assess gestational age has been described in several studies, which have shown that long bone measurements with CT correlate significantly with ultrasound estimates. A recent study described the use of PMCT for differentiating between still birth and live birth. In this study four cases are being described in which ‘distinction between live birth and stillbirth signs using PMCT was easily achieved’. Although no large validation study on determining the cause of death in children with PMCT has been performed yet, a recent study concerning unexpected death in children found that PMCT findings corresponded to autopsy in 89% of the cases. A validation study in adults showed a major discrepancy rate between postmortem radiology and autopsy findings of 32% in determining the cause of death. These studies were all performed shortly after death, when little or no postmortem changes are to be expected; it is unclear how PMCT performs in determining the cause of death after a longer postmortem interval with signs of severe decomposition. Some case reports have been published describing the possibility of determining a cause of death with PMCT after long postmortem intervals.

Normal postmortem cadaveric decomposition changes can a.o. cause putrefaction gas, which can be possibly misdiagnosed as pathological processes. If the possible additional value of PMCT in suspected neonaticide with late postmortem changes was quantified, this could improve current protocols for postmortem examinations. Therefore, we performed a retrospective study to compare non-contrast enhanced PMCT with autopsy in suspected neonaticide, in neonates found more than one week after their demise. We compared the performance of both methods on (1) determining gestational age, (2) differentiating between live birth and still birth and (3) determining cause of death.
MATERIAL AND METHODS
We selected all consecutive neonaticide cases with an estimated postmortem interval longer than one week, who underwent a forensic autopsy in the Netherlands Forensic Institute in the period 1-1-2008 to 31-12-2012.

External examination and autopsy
Autopsies were performed according to local protocol. Gender was determined with visual inspection of outer and inner genitalia and DNA investigations. Postmortem changes were classified as: (PM 1) minor postmortem changes: rigor mortis (partially) present, red or red-purple livor mortis; (PM 2) moderate postmortem changes: rigor mortis dissolved, fixed livor mortis, possible green color of the skin, minor swelling due to postmortem formation of gas, minimal detachment of the skin; (PM 3) severe postmortem changes: rigor mortis dissolved, assessment of livor mortis not possible, green-grey to black discoloration of the skin, possible severe swelling due to postmortem formation of gas, detachment of epidermis, nails and hair, smoothing of tissues and partial skeletonization. Furthermore they were classified according to the decomposition staging scale. This scale describes 10 different stages, with stage I-III being the putrid category, stage IV-VI being the bloating category, stage VII-VIII being the destruction category and groups IX-X being the skeleton category. If possible, foot length measurement was performed to determine gestational age. Reference values were obtained from ‘Fetal and neonatal pathology’. In the Netherlands, a fetus born at 24 weeks or later is considered potentially viable. If a fetus is born before 24 weeks of gestation, no person can be prosecuted for neonaticide. If possible, live birth was assessed according to protocol, by performing hydrostatic flotation tests of the lungs and gastrointestinal tract, assessment of the functional closure of the Botallian duct and histology (the presence of air in the alveoli). Histology, toxicology and DNA investigations were performed. Cause of death was classified according to the ICD-10 and according to the forensic classification used by the Netherlands Forensic Institute. All autopsies were performed by an experienced forensic pathologist (VS or AM) with extensive experience with pediatric forensic cases (8 and 15 years respectively).

PMCT
A total body non-contrast enhanced PMCT was performed shortly before autopsy, using a clinical state of art scanner (Toshiba Aquilon, Toshiba Medical Systems Europe B.V., Zoetermeer, the Netherlands or Philips Brilliance 64, Philips Healthcare, Best, the Netherlands). All studies were analyzed on a PACS system (Agfa Impax 6.4.0, Agfa Healthcare, Mortsel, Belgium). In all cases both MPR in the sagittal and coronal plane were performed. In order to measure the length of long bones, dedicated reconstructions were obtained along the long axis of the humerus, radius, femur and tibia. Additionally three dimensional surface shaded reconstructions were obtained. As this is a retrospective study, scan parameters were not identical in all cases, individual scan parameters are presented in table 1. In order to rule out the presence of rhizomelic or mesomelic shortening of
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the long bones, the diaphyseal lengths of the left, humerus, radius, femur and tibia were measured.\textsuperscript{24,25} The median gestational age and 5\textsuperscript{th} and 95\textsuperscript{th} percentile were assessed for each individual bone, based on reference values reported in ‘Fetal Radiology: a diagnostic atlas’.\textsuperscript{26} Gestational age was calculated based on femoral length, using the regression formula as presented by Scheuer et al.\textsuperscript{27} Aeration of the lungs and stomach, indicating live birth, was assessed and compared with gas localization elsewhere due to decomposition. Distribution of gas was assessed with the postmortem radiological alteration index (RAI).\textsuperscript{28} Cause of death was classified according to the ICD-10\textsuperscript{23} and according to the forensic classification used by the Netherlands Forensic Institute.\textsuperscript{18} All PMCT scans were assessed by an experienced forensic pediatric radiologist (RR) with 10 years of experience with forensic pediatric radiology.

\textbf{RESULTS}

Twenty-four autopsies on neonaticide cases have been performed in the Netherlands Forensic Institute in the period 2008-2012, of which 15 children (63\%) were estimated to be found more than one week after their demise. In 12 of these (80\%) cases a PMCT was performed and these were included in this study (Table 2). Eight of the children were found in a home, three were found nearby a home (e.g. garden or garden shed) and one was found in a meadow. The exact time between death and discovery of the body was unknown in most cases; based on testimonies during court proceedings it was estimated that this probably ranged between three weeks and seven years.

\begin{table}[h!]
\centering
\caption{Scan parameters}
\begin{tabular}{cccc}
\hline
Case number & Slice thickness (mm) & kV & mAs & Scanner \\
\hline
1 & 0.9 & 80 & 157 & Philips Brilliance 64 \\
2 & 0.5 & 100 & 200 & Toshiba Acquilon \\
3 & 0.5 & 100 & 50 & Toshiba Acquilon \\
4 & 0.5 & 100 & 50 & Toshiba Acquilon \\
5 & 0.5 & 100 & 50 & Toshiba Acquilon \\
6 & 0.5 & 100 & 50 & Toshiba Acquilon \\
7 & 1.0 & 140 & 179 & Philips Brilliance 64 \\
8 & 1.0 & 120 & 350 & Toshiba Acquilon \\
9 & 1.0 & 140 & 179 & Philips Brilliance 64 \\
10 & 3.0 & 120 & 239 & Philips Brilliance 64 \\
11 & 0.5 & 100 & 50 & Toshiba Acquilon \\
12 & 0.5 & 100 & 100 & Toshiba Acquilon \\
\hline
\end{tabular}
\end{table}
External examination and autopsy

In all cases, late postmortem changes were present, defined as PM 3 (Fig. 1a, 2a). According to the decomposition staging scale the postmortem changes in all cases were classified between VI and VIII. Sex could be determined with visual inspection in 8/12 cases (67%); in the other cases DNA investigations were performed; there were 3 boys and 9 girls. In 7 of the 12 cases (58%) it was possible to measure foot length. This was 71 mm on average, range 68-80 mm. This matches a mean gestational age of 36 weeks. In none of the cases it was possible to determine whether the neonate had been alive after birth. Due to postmortem changes it was not possible to perform flotation tests to assess aeration of the lungs or gastrointestinal air or assess functional closure of the Botallian duct. Interpretation of histological data was not possible due to autolysis. Toxicology and DNA investigations did not provide information that was helpful in determining the cause of death. In none of the cases it was possible to determine a cause of death; all were classified as XVIII R99 (other ill-defined and unspecified causes of mortality) according to the ICD-10. In three of the cases there were indications of potential suffocation or strangulation; in two cases a balled-up piece of clothing was tightly

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**Table 2. Characteristics of the cases**

<table>
<thead>
<tr>
<th>Case</th>
<th>Estimated pm interval</th>
<th>Decomposition staging scales</th>
<th>Location of discovery</th>
<th>Signs of violence</th>
<th>Siblings</th>
<th>Sex</th>
<th>Gestational age (in weeks) based on femur length</th>
<th>Mean (95% CI)</th>
<th>Gestational age (in weeks) based on foot length</th>
<th>Mean (Min–Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Months</td>
<td>VII</td>
<td>Home</td>
<td>-</td>
<td>M</td>
<td>40</td>
<td>(38–42)</td>
<td>39 (37–7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Unknown</td>
<td>VII–VIII</td>
<td>Home</td>
<td>-</td>
<td>F</td>
<td>37</td>
<td>(35–39)</td>
<td>35 (33–36)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5 years</td>
<td>VII</td>
<td>Home</td>
<td>-</td>
<td>*</td>
<td>M</td>
<td>39</td>
<td>(37–41)</td>
<td>n.e.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7 years</td>
<td>VII</td>
<td>Home</td>
<td>-</td>
<td>*</td>
<td>F</td>
<td>39</td>
<td>(37–41)</td>
<td>34 (33–36)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3 years</td>
<td>VII</td>
<td>Home</td>
<td>Clothing in mouth</td>
<td>*</td>
<td>F</td>
<td>39</td>
<td>(37–41)</td>
<td>n.e.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1 year</td>
<td>VII</td>
<td>Home</td>
<td>Clothing in mouth</td>
<td>*</td>
<td>F</td>
<td>40</td>
<td>(38–42)</td>
<td>35 (33–36)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Months</td>
<td>VII–VIII</td>
<td>Garden shed</td>
<td>-</td>
<td>#</td>
<td>F</td>
<td>37</td>
<td>(35–39)</td>
<td>34 (33–36)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1–5 year</td>
<td>VII</td>
<td>Garden (flowerpot)</td>
<td>-</td>
<td>#</td>
<td>F</td>
<td>33</td>
<td>(31–35)</td>
<td>n.e.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1–5 year</td>
<td>VII</td>
<td>Garden (buried)</td>
<td>-</td>
<td>#</td>
<td>M</td>
<td>38</td>
<td>(36–40)</td>
<td>35 (33–36)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5 years</td>
<td>VII</td>
<td>Home</td>
<td>-</td>
<td>F</td>
<td>39</td>
<td>(37–41)</td>
<td>n.e.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Unknown</td>
<td>VII–VIII</td>
<td>Meadow</td>
<td>-</td>
<td>F</td>
<td>37</td>
<td>(35–39)</td>
<td>n.e.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3 weeks</td>
<td>VI</td>
<td>Home</td>
<td>Cloth around neck</td>
<td>F</td>
<td>39</td>
<td>(37–41)</td>
<td>37 (35–39)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

95% CI, 95% confidence interval; Min, minimum; Max, maximum; M, male; F, female; n.e., not evaluable. Children born to the same mother are marked with an * or an #.
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stuffed in the mouth and in one case a piece of cloth was wrapped around the neck. As it was not possible to assess whether the child was alive at the moment that this happened, it was not possible to determine to what extent these findings contributed to the death of these children. Based on the circumstances in which the children were found, the cause of death was assumed to be (a form of) neonaticide in all cases, but stillbirth and abandonment could not be ruled out.

PMCT
In all cases, severe postmortem changes were present, defined as PM 3 (Fig. 1b-e). Gender could be determined in one case, in this case it matched the gender determined by the pathologist. In all cases it was possible to perform long bone measurements (Table 2, Fig. 1f, 2b). In one case the measurements were above the reference values provided in the literature. None of the children showed signs of rhizomelic or mesomelic shortening. All children were born at a potentially viable gestational age. In none of the cases it was possible to determine whether the neonate had been alive after birth due to late postmortem changes. The RAI is presented in table 3. In all cases, several sites (range 2-6) could not be assessed due to decomposition, therefore we did not calculate the index, as this method is only validated for 7 sites (Fig. 1d, e, 2b). For the same reason, in none of the cases neither a cause nor manner of death could be determined. The piece of cloth wrapped around the neck was recognized with PMCT, the t-shirt in the mouth of two children was not distinguishable from decomposing human remains with PMCT.
Chapter 12

DISCUSSION

The results of this study show that PMCT performs better in estimating gestational age compared to autopsy. Both PMCT and autopsy are unable to assess live birth and cause of death in case of late postmortem changes.

The major advantage of PMCT over autopsy in these cases is the rapid estimation of gestational age. In this study it was possible to estimate gestational age in 100% of the cases, compared to a 56% rate with autopsy. The only requisite is there should be identifiable and intact long bones. As decomposition of the skeleton occurs after a longer period of time than decomposition of the soft tissues, this method can be used in more cases than foot length measurement. After extraction and maceration, direct measurement of the long bones by an anthropologist is possible as well, but PMCT is faster, easier to perform and can be reassessed even after the neonate has been buried or cremated.

As decomposition hampers the assessment of signs of live birth and determination of cause of death in both PMCT and autopsy, none of the methods in this study was superior over the other to answer these questions. The fact that signs of live birth could not be determined by either method is understandable, as in both methods proof of life is demonstrated by the presence of air in lungs and/or digestive tract. Decomposition causes the presence of gas as well, and in many of our cases it was impossible to visualize the organs separately due to liquefaction, causing the distribution of air to be unreliable as well. Guddat et al. describe four cases with less severe postmortem changes, in which PMCT could assess the ratio between intrapulmonary air and air in other body parts and assist in the differentiating between live birth and stillbirth. Distribution of air has been proven to be useful in distinguishing between putrefaction and air embolism in adults. Our study did not include cases with little postmortem changes, and we did not find any studies describing the distribution of air in cases with severe decomposition changes.

Figure 2a. Neonate found in a meadow (case 11). There is severe decomposition (scale VII-VIII), note the absence of the head. Although the neonate was wrapped in plastic bags, numerous worms were found on the body (insert). The soft tissue overlying the pelvis is largely decomposed (arrow). Figure 2b. Coronal-oblique reconstruction along the shaft of the left femur shows complete decomposition of the thoracic and abdominal organs (limiting the use of the RAI). The length of the left femur is measured to assess skeletal age.
The fact that no cause of death could be determined with autopsy because of late postmortem changes is to be expected and has been described by others as well. It seems reasonable to assume and can be concluded from our results that the same holds true for determining the cause of death with PMCT. In autopsies with limited or no signs of decomposition, an advantage of autopsy above PMCT is the possibility of determining whether certain anomalies originated during life or after the demise. For example in injuries, bruising or hemorrhage around the injury indicates the incident must have happened while there was circulation. Differentiation between pre- and postmortem injuries is more difficult with PMCT. Although PMCT can detect hemorrhages around injuries depending on the size of those hemorrhages and the location of the injury and can therefore, in some cases, identify an injury as having been caused during life, the presence of a hemorrhage cannot be excluded with PMCT. Autopsy is a more sensitive method to detect this and therefore the method of choice to differentiate between pre- and postmortem injuries. In case of severe decomposition this advantage of autopsy is not applicable anymore, as late postmortem changes make it impossible to assess these aspects of injuries. In our study, two children had a t-shirt in their mouth. As signs of suffocation could not be assessed, it was not possible to conclude that the object in their mouth indeed contributed to their death. The same holds true for the child with a piece of cloth tied around the neck. Bruising, petechiae or other signs of strangulation could not be assessed; therefore interpretation of this finding was limited. Thus, in case of severe decomposition, the interpretation of PMCT and autopsy are more in keeping, compared to cases with a short postmortem interval, with respect to the assessment of live birth and determination of the cause of death.

Although generally seen as a valuable addition, replacement of autopsy by postmortem imaging does, at present, not seem feasible for the majority of (forensic) cases. In 2011 the first case report has been published in which postmortem imaging replaced a forensic autopsy, as both cause and manner of death were accepted by the authorities. In most countries this is not acceptable yet, but as postmortem radiology is a field that develops rapidly, this might be possible for certain cases in the future. Taking in regard the aim of a forensic autopsy in suspected neonaticide, an adjusted autopsy protocol might be considered in case of late postmortem changes. If PMCT is performed to estimate gestational age, an external autopsy or visual inspection of the body might be sufficient to gather all relevant information. This could be complemented with DNA investigations to determine kinship and sex (if the latter was not possible with CT/external inspection) and toxicological investigations to determine the presence of toxicological substances. In the 12 cases we describe this would have provided the same amount of information as a full autopsy.
CONCLUSION
In case of late postmortem changes, PMCT is superior in estimation of gestational age
compared to foot length measurement. There is no difference between PMCT and autopsy
regarding the assessment of live birth or cause of death; both modalities were unable to
determine these 2 parameters in any of the 12 cases in our sample. These results might
influence protocols for postmortem examination for suspected neonaticide in case of
severe putrefaction. PMCT is indispensable and should be performed compulsory; a full
autopsy might not always be necessary. We propose a new protocol for postmortem
examination, consisting of a PMCT, visual inspection and sampling for DNA, toxicological
and other forensic investigations.
REFERENCES