“Was the Infant Born Alive?” A Review of Postmortem Techniques Used to Determine Live Birth In Cases of Suspected Neonaticide

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ABSTRACT

The question of whether an infant was born alive has received much attention in the forensic literature. The volume of literature reflects the degree of controversy surrounding the techniques employed and their varied interpretation and utility. The majority of the investigation has been focused on the question “Has the infant breathed?” to determine if an infant was born alive by utilizing techniques that assess aeration of the lungs. However, caution must be employed when interpreting these techniques due to the well-recognized limitations in their interpretation, particularly in the presence of gaseous decomposition and/or resuscitation efforts. Although in some instances there may be irrefutable evidence that the infant was born alive, there is no single finding that can reliably be utilized to answer the question “Was the infant born alive?” in every case. Hence, the approach to postmortem investigation continues to include a wide range of observations, dissections, special techniques, and ancillary tests to assist the pathologist to form a considered opinion. There are a number of more recently described techniques which show great promise in assisting to answer this question including advanced imaging and immunohistochemical studies of the umbilical cord. It remains, though, that in many cases it is not possible to definitively answer this question and stillbirth should be assumed due to the potential legal implications of determining that an infant was born alive. *Acad Forensic Pathol.* 2018 8(4): 874-893

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INTRODUCTION

Neonaticide is defined as the deliberate killing of a newborn infant in the first 24 hours of life (1). The perpetrator is typically the mother (2). In many jurisdictions, the offense has reduced culpability due to the widely held belief that the psychological effects of birth and lactation can have an impact on the mother's state of mind. Although cases of neonaticide are rare, they are invariably high profile, being associated with intense media scrutiny and public attention.

Medicolegal death investigation in Australia operates under the Coronial system. The Coroner is legislated to investigate deaths that fall within their jurisdiction. As part of their investigation, the Coroner is required to determine who the deceased person is, how the person died, when the person died, where the person died, and what caused the person to die (3). The forensic pathologist is ordered by the Coroner to perform postmortem examinations on deceased individuals to assist them in this investigation. Neonatal deaths are a special circumstance where the Coroner may or may not have jurisdiction depending on a number of factors, firstly and perhaps most importantly, whether the infant was born alive. In Australia, the Coroner does not have jurisdiction to investigate deaths of stillborn infants. Where there is uncertainty around this, however, they are able to order a postmortem examination to determine if the infant was live born. The Coroner's investigation must cease if there is a determination of stillbirth.

Due to legislative differences, there is variation in how neonatal deaths are managed and prosecuted from one jurisdiction to the next. There are also subtle variations in the definition of live birth and separate existence. According to Knight, "separate existence" refers to signs of life in an infant completely expelled from the maternal passages (independent of the placenta), whilst "live birth" refers to signs of life in an infant regardless of whether they have been completely expelled from the maternal passages (1). It is not possible to distinguish separate existence from live birth in the absence of a witness. The World Health Organisation (WHO) defines live birth as:

The complete expulsion or extraction from its mother of a product of conception, irrespective of the duration of the pregnancy, which, after such separation, breathes or shows any other evidence of life – e.g. beating of the heart, pulsation of the umbilical cord or definite movement of voluntarily muscles – whether or not the umbilical cord has been cut or the placenta is attached (4).

In practice, this definition is often simplified and live birth is taken to be the attainment of breathing air. In order to prosecute a case of neonaticide, it must first be shown that an infant was born alive.

The incidence of neonaticide varies from one jurisdiction to another due to differences in social, economic, cultural, and religious factors. Herman-Giddens et al. reported a rate of 2.1 neonaticides per 100 000 live births in North Carolina between 1985 and 2000, accounting for 0.002% of live born infants in the region (5). However, the true incidence of neonaticide in any given population is considered to be underestimated. This is due to the nature of the cases that do come to the attention of authorities, usually involving bodies that are discarded, concealed, or buried in rubbish bins, rubbish dumps, public toilets, lakes, sewage plants, or woodlands (1, 5-7). In some cases, the body is discovered many years later. Hence, it can be inferred that there are many cases where the body is never discovered and the death does not come to the attention of authorities. For this reason, it is near impossible to give an estimate of the true incidence of neonaticide.

The cause of death in neonaticides can broadly be divided into deliberate acts and omissions of care. They generally occur immediately after birth and the most common causes are reported to be neglect, inattention/exposure, asphyxia, drowning, stabbing, and blunt head trauma (5-7). The usual scenario is of an abandoned infant, where the identity of the mother is unknown. In the majority of cases, the infant is found in a concealed location, wrapped in varying materials, and partially decomposed. In some instances, a case may come to the attention of the authorities earlier

due to postpartum complications in the mother (8). The mother, if identified, is usually young, unmarried, and primiparous, with a concealed pregnancy and an unassisted birth (1, 2, 5, 6). The task of the forensic pathologist in these cases is to assist to identify the mother, determine if the infant was born alive, and determine the cause (and in some jurisdictions, the manner) of death (1, 7, 9, 10). For the purposes of this review the focus will be on determining “Was the infant was born alive?”

This topic has received much attention in the forensic literature as our knowledge and understanding of the reliability and limitations of various findings and techniques has evolved. At present, it is widely accepted that there is no single finding or combination of findings, short of a reliable (preferably medical) witness, that indicates an infant was definitely born alive. The assessment is approached with meticulous care and great caution with the postmortem findings generally considered in combination when forming an opinion as to live birth or stillbirth. It is now well recognized that changes of decomposition can hinder the assessment by producing gaseous artifact and that this is present in a large proportion of suspected neonaticide cases. In Germany, severe decomposition was described in 27% of (suspected) neonaticides (11).

Plain film imaging has assisted our understanding of the limitations of postmortem assessment due to the demonstration of air as a postmortem artifact. In 1969, Hiroven et al. used plain film to demonstrate the predictable movement of air through the gastrointestinal tract of newborn infants. He further demonstrated that stillborn infants had no gas in the lungs or gastrointestinal tract on plain film immediately after birth; however, after artificial respiration with a mask some infants showed air in the lungs and or gastrointestinal tract. These results showed that artificial respiration can introduce air into the lungs and gastrointestinal tract leading to potential error in the interpretation of autopsy findings including imaging and the lung flotation test (12). It is now widely accepted that resuscitation efforts can complicate the assessment of live birth in neonatal deaths.

DISCUSSION

In cases of suspected neonaticide, the circumstances and scene investigation are integral to understanding the scenario and determining if an infant was born alive. These findings may assist the forensic pathologist in interpreting the postmortem findings.

The postmortem examination follows the usual protocol of dissection and ancillary testing undertaken in all sudden unexpected deaths in infancy (SUDI), including examination of the placenta when available. In addition to this, there are a range of specific observations, dissections, special techniques, and ancillary tests specifically aimed at answering the unique question “Was the infant born alive?” The findings are considered to be of variable accuracy and can be classified into four groups according to their utility: findings that preclude live birth, findings that indicate potential birth complications, findings that indicate possible live birth, and findings that prove live birth.

These findings can be considered in combination when forming an opinion as to whether an infant was born alive.

Findings that Preclude Live Birth

A logical place to commence is with identification of findings that are incompatible with life and thus preclude live birth. In Queensland, stillbirth is defined as the birth of a baby who shows no signs of life after a pregnancy of at least 20 weeks gestation or weighing 400 g or more. Miscarriage refers to the loss of a pregnancy prior to 20 weeks gestation. If the forensic pathologist determines miscarriage or stillbirth, the Coroner’s investigation is concluded (3, 13).

Findings that fall into this category include: the presence of maceration indicating intrauterine fetal demise, low gestational age that is incompatible with extrauterine life, or a lethal malformation that is incompatible with extrauterine life.

Maceration

Maceration is the process of sterile tissue breakdown that occurs if an infant is dead for a period of time in the uterus. It differs from decomposition, which is the process of autolysis and putrefaction that occurs after death due to the actions of enzymes and microorganisms in the body. The finding of maceration is indicative of intrauterine fetal demise and indicates that the infant was not born alive.

Changes of maceration are initially seen as brown–pink discoloration of the skin, followed by skin blistering, hyperextensible joints, and eventually collapse of the skull (2, 6). Maceration is a common finding in cases of stillbirth and is a familiar site to pathologists who perform regular perinatal postmortem examinations.

Gestational Age Incompatible With Extrauterine Life

With advances in science and modern medicine, infants of diminishing gestational age can be supported and managed under specialist neonatal intensivists in tertiary hospitals. Hence, the definition of nonviable gestation, inconsistent with extrauterine life, is considered in the context of contemporary scientific and medical knowledge. Currently, extreme prematurity of less than 23 weeks gestation is generally considered inconsistent with extrauterine life (14). This is mainly due to immaturity of the lungs. However, without intensive medical intervention, fetuses of more advanced gestation are not capable of sustaining life.

There are a number of tools that can be utilized to determine gestational age. These include the following:

Haase's rule:

The length of the foetus in centimetres is approximately the square of the age in months up to the 20th week. Beyond the 20th week, the length in centimetres divided by five represents the age in months (1).

Obstetric records: access to obstetric records is considered the exception rather than the rule. In many cases, the mother will not be identified and even when identified, the mother will usually have had little or no antenatal care. When available, however, antenatal scans and blood tests may assist with approximating gestational age.

External measurements: the assessment of morphological measurements including body weight, body length, and foot length to estimate gestational age can be performed fairly rapidly and compared with standardized population-based tables to estimate gestational age (15). This is only a guide, however, due to known variations attributable to sex, race, and nutritional status as well as variation due to postmortem change (16).

Fetal ossification centers: fetal ossification centers can be used as predictors of gestational age. Whilst traditionally assessment of ossification centers was undertaken at postmortem examination by dissection and direct visualization, they are now more easily assessed by a pediatric forensic radiologist on skeletal survey and/or using advanced postmortem imaging techniques. Where available, postmortem computed tomography (PMCT) is a rapid and accurate way of estimating gestational age and creates a permanent digital record of findings. Sieswerda-Hoogendoorn et al. looked at 12 neonaticide cases with an estimated postmortem interval of one week and compared the ability to determine gestational age by PMCT with that of autopsy. They found that PMCT was able to determine gestational age in 100% of cases compared with 58% at autopsy (9).

Placental examination: assessment of chorionic villous maturity can be used as an indicator of gestational age; however, this is not specific and is not considered a reliable finding.

Internal examination: examination of the internal organs can assist in estimation of gestational age using weights, macroscopic appearances, and histological features. Organ weights can be compared with standardized population-based tables to estimate gesta-

tional age (15); however, organ maturation is considered to be a more reliable indicator of gestational age. The macroscopic convolutions of the fetal brain have been shown to correlate well with gestational age with accuracy within one week gestation (17). Histological appearances of the glomeruli in the kidneys can also be useful in assessment of fetal maturation (18).

Lethal Malformations

The finding at postmortem examination of a lethal malformation or a condition that precludes independent existence can assist in determining if an infant was born alive. Such conditions include anencephaly, pulmonary hypoplasia, skeletal dysplasias, and chromosomal malformation syndromes. There are also a number of other conditions such as diaphragmatic hernia, severe neural tube defects, and congenital cardiac defects that, whilst not immediately life threatening, would certainly result in rapid demise in the absence of immediate medical intervention at birth.

Findings that Indicate Potential Birth Complications

Identification and documentation of risk factors for prematurity, perinatal asphyxia, intrapartum death, and/or stillbirth may assist the pathologist in forming an opinion as to live birth. There are also findings in the infant, umbilical cord, and/or placenta that are known to predispose to or indicate potential peripartum complications such as obstructed labor or birth trauma.

Findings that fall into this category include signs of intrauterine fetal pathology, signs of birth trauma, and risk factors for stillbirth.

Signs of Intrauterine Fetal Pathology

There may be signs in the placenta and/or neonate that indicate intrauterine fetal distress or intrauterine fetal demise.

It is well recognized that examination of the placenta forms an integral part of the postmortem exam-

ination in all neonatal deaths. Possible abnormalities of the placenta include evidence of placental abruption, chorioamnionitis, meconium staining, placental insufficiency, and/or maternal pathology (16, 19). Apart from the usual sampling and examination that is undertaken in hospital perinatal deaths, there are also some additional forensic observations to be considered in the context of potential birth trauma (see below). Examination of the placenta by the forensic pathologist in consultation with a specialist pediatric surgical pathologist may be indicated.

Meconium is the dark green, sticky, tar-like first stool passed by an infant. The presence of dark green staining of an infant's skin or beneath the nails is considered an indication of meconium stained liquor, a marker of intrauterine fetal distress. There may also be evidence of meconium aspiration in the lungs (See **Images 1A-1C**).

Signs of Birth Trauma

There are typical injury patterns that are associated with traumatic births such as precipitate delivery, shoulder dystocia, and breech presentation. The recognition of these may be helpful to assist in understanding the circumstances of birth and determining whether an infant was born alive.

Precipitate labor refers to an unusually rapid labor with expulsion of the fetus, usually within two hours of onset. The delivery can result in the infant having impact with the ground (or other surface) causing blunt force trauma, usually to the head. This has been described in scenarios when the mother is standing during delivery and when there is a long umbilical cord (6, 20). Fractures of the skull or clavicle may also be attributed to birth trauma due to instrumentation, cephalopelvic disproportion, shoulder dystocia, or fetal macrosomia (16). Birth trauma-related skull fractures are usually linear fractures of the parietal bone and can be associated with extradural hematoma.

Other head injuries associated with birth trauma include occipital osteodiasis and neural tears. Occipital osteodiasis is a rare complication where there

is separation of the occipital bone at the back of the skull with tearing of the venous sinuses and associated subdural hemorrhage that can occur during difficult breech delivery (16). Neural tears can occur as a result of birth-related head trauma associated with excessive or rapid molding of the fetal head during delivery. It is also important to note that retinal hemorrhages are commonly described in otherwise normal live newborns (16). Breech delivery can result in damage to the internal organs including the liver, spleen, and kidneys due to pressure on the infant's abdomen during attempts at delivering the head.

Peripartum umbilical cord accidents can be related to the length or integrity of the umbilical cord. Short umbilical cords are associated with birth asphyxia, whilst long umbilical cords are associated with nuchal cord

and prolapse of the umbilical cord with subsequent obstruction of the fetal-placental circulation. Poor integrity or damage of the umbilical cord can lead to rupture of the umbilical vessels and exsanguination (6).

The appearance of the umbilical cord ends can also give information about the circumstances of birth and delivery. The presence of a clamp may be indicative of medical intervention, whilst the presence of tearing at the cord ends, in conjunction with other findings, may be consistent with a precipitate delivery. Knight suggests submersing the cord in water to assist in determining if it is torn (1). Tearing of the umbilical cord before or during labor can result in massive hemorrhage and subsequent fetal death (16).

Image 1A: Meconium aspiration (H&E, x200).

Marks around an infant's neck may raise concern regarding strangulation; however, marks under the chin and on the sides of the neck have reportedly been seen in association with attempts by the mother to extract the infant from the birth canal during self-delivery (1, 6, 7, 20).

Other birth-related findings include cephalohematoma and caput succedaneum. Cephalohematoma is a lump on the scalp that can occur due to traumatic subperiosteal hemorrhage that occurs when there is pressure on the fetal head during delivery, whilst caput succedaneum is edema of the scalp that can occur during difficult prolonged labor (6).

The timing of various injuries, whether antepartum, peripartum, antemortem, or postmortem, may be dif-

ficult to ascertain, but evidence of a vital reaction on histological assessment may be supportive of a period of survival after sustaining the injury and, hence, live birth. That being said, the absence of a vital reaction cannot be used to negate live birth. This assessment may be complicated by postmortem change such as decomposition, as it is well recognized that histological assessment is limited in the presence of autolysis and putrefaction.

Risk Factors for Stillbirth

There is a high rate of stillbirth worldwide with the WHO reporting 2.6 million babies were stillborn in 2015, equating to 18.4 stillbirths for every 1000 live born infants. Although rates are markedly lower in countries like the United States and Australia, with

Image 1B: Meconium aspiration (Atwood stain, x200).

rates of 3.0 and 2.7 stillbirths per 1000 total births respectively, stillbirth is not an uncommon outcome of pregnancy (21).

Identification and documentation of risk factors for stillbirth is a pertinent part of the examination. These are generally divided into fetal conditions, maternal conditions, and problems with the placenta. Conditions in the fetus include lethal malformations, chromosomal or genetic disease, structural abnormalities, and infections. In the placenta, significant findings include infarction, hemorrhage, and placental villous dysmatruity.

If the mother is identified, the medical and obstetric history can be scrutinized for maternal risk factors of stillbirth. These include a past obstetric history of

perinatal death, primiparity, lack of antenatal care, a multiple pregnancy, diabetes mellitus, smoking, obesity, maternal age (<15 years or >35years), substance abuse, socioeconomic disadvantage, and some maternal infections (e.g., Zika virus) (22).

Findings that Indicate Possible Live Birth

The signs of live birth that have received most attention in the literature include evidence that the infant has breathed, healing of the umbilical stump, and food in the stomach. The first two of these signs are considered to be indicators of potential live birth and will be discussed in this section. Food in the stomach is widely considered to be an irrefutable sign that the infant has been born alive and will be considered in the section “Signs that prove live birth.”

Image 1C: Congenital pneumonia (H&E, x200).

Surrogate Markers of Breathing

Throughout history, the majority of literature on the assessment for live birth has focused on examination of the infant's lungs. There are numerous documented approaches to assessing the lungs for signs that an infant has taken a breath. These include techniques involving gross morphology, the lung flotation test, histological examination, and imaging.

As previously mentioned, it is now well recognized that there are limitations when using the anatomical assessment of the lungs to indicate whether the physiological process of breathing has occurred. There are other notable reasons for aeration of the lungs in an infant including the introduction of air during resuscitation attempts and gas formation due to changes of decomposition. The presence of either of these should be noted and acknowledged when assessing for surrogate signs of breathing.

It is important to be aware that lungs of stillborn neonates can appear aerated at postmortem and lungs of live born infants can be devoid of air (19). Hence, short of medical observation of breathing after birth, all other signs are considered surrogate anatomical markers of breathing and interpreted with caution in the context of other findings. According to Neri et al., "*Ventilation of the lungs alone cannot be taken as a certain marker of live birth*" (see **Table 1**) (23).

Lung Morphology

At postmortem examination, the gross appearances of the lungs of stillborn and live born infants differ. Upon opening the chest plate, stillborn infant lungs are usually contracted against the mediastinum. They

are often described as dark and small with a "liver-like" appearance. The lung margins have a sharp, angled appearance and the parenchyma has a uniform rubbery consistency with absence of crepitation on palpation. If the infant has breathed, the medial edges of the lungs are said to overlap at the mediastinum on opening the chest plate. They are described as having a salmon-pink, mottled appearance. The lung margins have blunt angles and the lung parenchyma has a spongy consistency with crepitation on palpation (1). Although these descriptions are quite distinct from one another, in practice, the morphology of lungs from stillborn and live born infants are probably best represented by a continuum with the classical findings at each end. It seems feasible that an infant would require several substantial breaths before the lungs expand completely and show the full spectrum of findings expected for a live born infant lung (7).

Tabata et al. considered the finding of froth in the airways of a newborn infant found in a freezer and thawed to represent respiratory distress, and hence indicate live birth (24). Although the combination of pulmonary edema and froth in the airways may represent mixing of pulmonary edema with inspired air, caution should be observed when drawing this conclusion due to the potential for froth in the airways being attributable to putrefactive artefact (6).

Lung Flotation Test

Historically, determination of live birth was considered to be largely dependent on the result of the lung flotation test, also known as the "lung test," "flotation test," and "hydrostatic test." It is believed that the test was initially formalized in the 1600s, though there is variation in the literature as to who it is ascribed (25). Whilst some papers identify the first to use the test as German doctor Johannes Schreyer in 1681 (10, 26), others recognize Dutch scientist Jan Swammerdam in 1667 (25).

The test is based on the premise that if an infant has breathed then the lungs will be inflated. Hence, if the lungs float when placed in water, this indicates that they are inflated and the infant had breathed and was

Table 1: Surrogate Markers of Breathing

Lung morphology
Lung flotation test
Lung histology
Postmortem imaging
*Plain film
*Postmortem computed tomography
*Postmortem magnetic resonance imaging

born alive. If the lungs sink when placed in water, the lungs are not inflated and the infant had not breathed and was stillborn.

Over time there have been innumerable variations to the procedure for performing the lung flotation test (25) including: variations in the temperature of the water used for flotation; flotation of the entire thoracic block, individual lungs, individual lung lobes, and/or pieces of lung; flotation of a piece of liver to assess for gaseous decomposition, where if the liver floats, the lung flotation test is considered inconclusive (27); flotation of the stomach and intestines to demonstrate air in the gastrointestinal tract attributed to swallowing, though it has since been recognized that air in the gastrointestinal tract can also be artefactual due to resuscitation or gaseous decomposition (6, 7, 28); and ligation of airways and/or pulmonary vessels prior to flotation (19, 20, 25, 26).

The test has received much attention in the literature with many papers proffering an opinion as to its validity. Whilst initially there was a great emphasis on the lung flotation test in determining live birth, the test received much scrutiny in Germany and France at the turn of 20th century after a finding that the lungs of an infant known to be live born sank (10). Around the same time, it became evident that a false positive flotation test could occur in the context of gas production due to postmortem decomposition. This potential for false positive results in the context of gaseous decomposition is now well recognized and pathologists are cautioned to interpret the result in the context of the history and postmortem change (1, 2, 7, 20). The potential for false negative results was highlighted in a prospective study of hospital births where Große Ostendorf et al. found the lung flotation test to be negative in four of 14 live born infants. This was postulated to be due to prematurity and/or significant illness in these cases (26).

Knight concludes that:

The test is of limited value, whatever modifications are made and it can at best be a suggestive pointer, but never a definitive test in itself (1).

When performed, the limitations of the test should be acknowledged.

Lung Histology

The implementation of microscopic examination of the lungs to assist in determining live birth came into popularity in the mid 1900s. It was purported that aeration of the alveoli was indicative of live birth, whilst uniformly unaerated alveoli was indicative of stillbirth. However, this notion has since received criticism due to the finding of atelectasis in the lungs of infants known to have been born alive and apparently aerated alveoli in infants known to have been stillborn. According to some studies, the histological appearance of the alveoli is more indicative of fetal maturity than the presence of respiration (15, 29).

There is also the potential for artefactual appearances within the lungs at histological examination. Not only are there the usual complicating factors of decomposition and resuscitation that have potential to alter the histological appearances, changes may also be attributed to handling at postmortem examination. It has been postulated that the process of evisceration can potentially introduce air into the lungs and that handling of the tissue during morphological examination of the parenchyma and/or during the implementation of special techniques has the potential to cause artefactual collapse of alveoli.

There is disagreement surrounding the utility of assessment of the histological expansion of the lungs within the literature, with differing opinions as to the merit of this finding. Some maintain that evidence of lung aeration under the microscope, in the absence of resuscitation or decomposition, is indicative of live birth and that uniformly unaerated lungs equate to stillbirth. Others attest to uniformly expanded lungs being indicative of respiration or resuscitation, whilst the finding of partially expanded lungs is equivocal (6). There is a further opinion that whilst the assessment may be helpful, it should not be used as definitive evidence of live birth (16, 19, 29, 30). Di Maio states that “*Microscopic sections of the lung are of no help in determining if a child breathed*”, citing cases

of diffuse atelectasis in infants known to be born alive and open alveoli in infants known to be stillborn (2).

Another finding in lung histology that has been utilized in assessing for signs of live birth is that of pulmonary interstitial emphysema (PIE). Pulmonary interstitial emphysema is a condition where there is accumulation of gas forming pleural blebs and pneumothoraces secondary to alveolar wall rupture and tracking of air in interlobular pulmonary vascular sheaths. It can be seen in premature infants receiving mechanical ventilation and has also been associated with congenital cystic lesions, severe pulmonary infections, and resuscitation (19). It has been postulated by Lavezzi et al. that PIE may be indicative of live birth. In a study of 87 infants (66 live born and 21 stillborn), they were able to demonstrate florid PIE in 16 live born infants, however 12 of these received cardiopulmonary resuscitation and/or mechanical ventilation. None of the stillborn infants showed florid PIE, but “equivocal” PIE was demonstrated in infants from both groups (28, 31). Although this study outlines a promising finding, the utility of PIE in determining live birth is not yet established. There are also likely to be similar caveats to its interpretation in the context of gaseous decomposition and resuscitation.

Postmortem Imaging

The utility of postmortem imaging in pediatric forensic death investigation is widely acknowledged, with the major advantage being that it can occur prior to commencing conventional autopsy without disruption to the body. Radiographic images are usually reported by a pediatric radiologist and the report made available to the pathologist prior to the commencement of invasive autopsy (16). With the widespread utilization of advanced imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI), some centers now offer “virtual autopsy” services for investigation of hospital perinatal deaths. In light of this, many hospital pediatric radiologists have increasing experience in reporting postmortem imaging of stillborn infants. With this expansion of postmortem imaging knowledge, the applicability of advanced imaging techniques to the forensic setting is

beginning to be realized. Many forensic centers now have access to a CT scanner, whilst some have access to an MRI scanner. In these jurisdictions, the implementation of advanced imaging in forensic cases, in particular pediatric and neonatal cases, has shown promising results.

Plain Film

In many forensic mortuaries, plain film remains the only imaging modality available and skeletal surveys are performed in these cases. Radiographs can show aeration of the lungs and the presence of gas in the stomach prior to autopsy and, when used in conjunction with postmortem examination, have been shown to correlate with the pathologist’s findings at postmortem. These findings can be used in combination to favor live birth (6, 12).

Postmortem Computed Tomography (PMCT)

More recently, the implementation of PMCT imaging has been used to detect the presence of gas in the infant. It is superior to plain radiographs in determining the distribution pattern of air in the lungs, gastrointestinal tract, and liver and has been shown to have good agreement with the lung flotation test (20, 27, 32). Gas in the stomach and upper gastrointestinal tract along with uniform gas distribution within the lungs on three-dimensional reconstruction of PMCT provides convincing evidence that a neonate has breathed naturally prior to demise and was, therefore, live born (20). The extent of aeration of peripheral alveoli is easily observable on PMCT, making this a useful tool for the possible differentiation between artificially and naturally aerated lungs.

Guddat et al. demonstrated visualization of completely aerated lungs on PMCT in a one-day-old infant and in two cases of suspected neonaticide where live birth was confirmed (independently of the medicolegal investigation), showing that PMCT can be used as an adjunct to determine live birth in neonates (20).

In a study of seven infants (three live births, one stillbirth with unsuccessful cardiopulmonary resuscitation

tion, one spontaneous abortion, two intrauterine fetuses), Michiue et al. found that live born infants who died in the early neonatal period had poor aeration of the lungs (32). In one case, this was attributed to congestion/edema due to a congenital heart anomaly and in another to diffuse atelectasis due to respiratory distress. The stillborn infant that received artificial ventilation showed uneven lung gas distribution with markedly different lung volumes, uneven alveolar expansions, and a large amount of gastrointestinal gas (See **Images 2A-2D**) (32).

The limitations of PMCT imaging are similar to those of other techniques with the presence of decomposition gas potentially obscuring findings. With increased experience in interpreting PMCT images, the progression of decomposition gas is now understood to have an unpredictable time course dependent on characteristics in the body and the environment. It usually commences in the intestines and portal vasculature of the liver, before progressing to involve all vasculature, structures, and anatomic spaces (33). Hence, PMCT findings can be interpreted in the context of these changes. Assessment of the extent of decomposition on PMCT can also be used to assist in determining the validity of other results that are known to be affected by gaseous decomposition, for example the lung flotation test.

Postmortem Magnetic Resonance Imaging (PMMRI)

The majority of the literature on PMMRI of the fetus is focused on its use as a technique for the replacement of invasive autopsy in the face of declining perinatal autopsy numbers. In these studies, its utility in detecting major pathological abnormalities and determining cause of death in hospital perinatal deaths has been demonstrated. It has shown particular use in evaluating abnormalities of the central nervous system but is of limited use in complex cardiac malformation (34-36).

To date, there is sparse literature on the use of PMMRI for the determination of live birth. In 2015, Barber et al. published a retrospective case series using PMMRI to look at the aeration of lungs in 42 infant deaths (19

live births and 23 stillbirths) and found 17 true positive and 22 true negative results. The single false positive result was in an infant where it was unclear whether resuscitation had been administered, highlighting a widely recognized limitation when assessing aeration of the lungs. There were two false negative results in which there was documented spontaneous breathing in the neonate but no gas in the lung parenchyma on PMMRI (37). Although further studies are required to validate these findings, the paper suggests promise for the future of PMMRI in assisting to determine whether an infant was born alive.

Postmortem Imaging Summary

There are inherent advantages of imaging in that it is rapid, noninvasive, and forms a permanent record which can be reviewed long after the body has been buried or cremated. In light of the sensitivity of this forensic question and the promising results of both PMCT and PMMRI in determining aeration of the lungs, accessing advanced imaging techniques whenever possible can augment the investigation and assist the pathologist in forming an opinion as to live birth.

Healing of the Umbilical Cord Stump

Morphological examination of the umbilical cord stump is undertaken to assess for signs of a vital reaction, which are considered to indicate a period of survival. The umbilical cord stump undergoes a series of changes in the first days of life with formation of a reddened ring at the base of the cord, followed by drying, shrivelling, and eventually detachment of the stump after several days. The earliest macroscopic signs of a vital reaction are generally visible at 24-48 hours of life with early changes of separation, reddening, and desiccation.

Histological sections of the umbilical stump can be taken to assess for microscopic evidence of a vital reaction. The presence of inflammatory infiltrates has been described as early as three hours postpartum in infants that were live born (38). Janssen reported that two to three polymorphonuclear leucocytes per intermediate magnification represent evidence of a vital

Image 2A: Postmortem computed tomography image of unaerated/radioopaque lungs from an infant with no signs of life after delivery.

Image 2B: Coronal average intensity projection postmortem computed tomography image of unaerated/radioopaque lungs from an infant with no signs of life after delivery.

Image 2C: Postmortem computed tomography image of aerated lungs from a 1-day-old infant.

Image 2D: Coronal average intensity projection postmortem computed tomography image of aerated lungs from a 1-day-old infant.

reaction, however cautions that this finding should not be taken in isolation, citing reports of post-mature stillborn infants showing umbilical inflammatory reactions (19). Adelson considers the presence of a vital reaction in the umbilical cord stump to be one of the irrefutable criteria of postnatal survival (39), but in light of Janssen's findings, a more conservative approach is advised, particularly in the context of postmortem artifact such as decomposition, where assessment for the signs of maceration is hindered.

A finding more definitive for live birth is the presence of thrombosis within the umbilical cord vasculature, particularly when there are features of organization. The absence of thrombosis, though, cannot be inferred to indicate stillbirth (19).

More recently, studies looking at immunohistochemical (IHC) staining patterns of the umbilical cord have shown promising results in differentiating live born from stillborn infants (1, 6). In a study of 45 umbilical cords comprising 24 stillborn (14 died *in utero*, ten during labor) and 21 live born infant umbilical cords sampled during delivery, Neri et al. showed statistically significant IHC staining for tryptase, CD68, and α_1 -antichymotrypsin with widespread expression in the cords of live born infants (23). This technique shows great promise in identifying live born infants, however additional studies are required to validate these results in umbilical cord stumps at the interface between the cord and the fetal skin. Whilst most forensic pathology histology laboratories are unlikely to have these IHC stains, gaining limited access to them from other laboratories may prove useful in these contentious cases.

Findings that Prove Live Birth

Although it is arguably not possible to "prove" live birth without witnessing signs of life, there are a few postmortem findings that leave little doubt that an infant was born alive.

Food in the Stomach

Food in the stomach is widely considered unequivocal evidence that an infant was born alive and survived for a period of time. The consumption of food is an active process requiring the infant to suck, hence the finding of food in the stomach or anywhere along the gastrointestinal tract is considered a definitive finding.

Unfortunately, in most cases of neonaticide, the death is thought to occur within hours of birth and the finding of food in the stomach is rarely present. However, these cases present little problem for the pathologist.

Pathological Conditions That Indicate a Period of Survival

The presence of pathological conditions in the neonate that only occur after birth indicate a definite period of survival. For example, starch particles or other food material in the lungs is indicative of vital perimortem aspiration and is considered evidence that an infant was born alive (19). Also, hyaline membrane disease has only been observed in the lungs of infants born alive. Pulmonary hyaline membranes are membranous linings of the alveolar spaces which cause respiratory distress. They require respiration to form and are considered evidence that the infant has lived (See Table 2) (6, 19).

Table 2: Classification of Postmortem Findings Used to Determine Live Birth

Findings That Preclude Live Birth	Findings That Indicate Potential Birth Complications	Findings That Indicate Possible Live Birth	Findings That Prove Live Birth
Maceration	Signs of intrauterine fetal pathology	Surrogate markers of breathing	Food in the stomach
Gestational age incompatible with extrauterine life	Signs of birth trauma	Healing of the umbilical cord stump	Pathological conditions that indicate a period of survival
Lethal malformations	Risk factors for stillbirth		

CONCLUSION

The postmortem examination in suspected cases of neonaticide is complicated by the unique question “Was the infant born alive?” that must be answered to successfully prosecute these cases. There are a plethora of observations, dissections, special techniques, and ancillary tests that have been implemented in attempts to definitively answer this question. The classification of these findings into the broad groupings: findings that preclude live birth, findings that indicate potential birth complications, findings that indicate possible live birth, and findings that prove live birth, can be used to highlight the differing underlying rationale used when applying these findings and their potential utility. Findings that “preclude” or “prove” live birth are of greatest utility in forming an opinion as to live birth in cases where they are present. Whereas, findings indicating “potential birth complications” or “possible live birth” are considered less definitive and should be considered in conjunction with other findings in the context of the case when forming an opinion.

In a large proportion of cases, the neonate is discovered in a concealed location in unclear circumstances with varying degrees of postmortem change that hinder the assessment. Changes of decomposition are a major stumbling block when attempting to assess a neonate for evidence of being born alive. Throughout the literature, much emphasis is placed on answering the question “Has the child breathed?” using aeration of the lungs as a surrogate marker for being born alive. It is now widely accepted that resuscitation efforts and decomposition effect aeration of the lungs and, hence, the interpretation and validity of tests that utilize this as a surrogate marker of live birth. In light of these limitations, arguably too much emphasis is placed on the aeration of the lungs in forming an opinion as to live birth.

This review highlights the promising utility of advanced imaging techniques in the assessment of live birth using the distribution of air in the lungs in conjunction with assessment of gaseous decomposition.

Additional studies will increase our understanding of the validity of these images in a range of circumstances. The lung flotation test, despite its controversies, has been repeatedly shown to be of use if the limitations are observed. When used in conjunction with postmortem imaging, these results give a complimentary understanding.

The other promising area of assessment is histology of the umbilical cord, with the use of IHC staining to differentiate live born from stillborn infants. Further work in this area will assist in establishing the utility of tryptase, CD68, and α_1 -antichymotrypsin IHC in determining live birth.

The low incidence and small number of these cases in any given jurisdiction is a barrier to the pathologist’s exposure to and experience in assessing these cases. Many of the more recent studies have used nonforensic pediatric cases from hospital perinatal postmortem cases where there is a medically documented history to validate findings. This approach is considered necessary to obtain robust data that can be extrapolated to use in forensic cases where the circumstances and history are unclear. However, one limitation of this is that these cases do not have features of decomposition which usually complicate the assessment in the forensic setting.

Overall, “Was the infant born alive?” remains a difficult forensic question to be approached with great caution. Other than a witness to live birth, there is no single test that can reliably determine whether an infant was live born and a number of findings are often combined to assist in forming an opinion. The usual processes of thorough documentation and peer review are pertinent in these cases; however, retrospective determination that an infant was born alive, based solely on autopsy findings, is a difficult task and in many cases the question of live birth simply cannot be answered definitively. In these cases, stillbirth should be assumed (6, 38). A false positive result is of the most significant concern due the legal implications of an incorrect determination of live birth possibly resulting in wrongful conviction.

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