

PAEDIATRIC FORENSIC MEDICINE AND PATHOLOGY

Edited by

Anthony Busuttil

*Regius Professor of Forensic Pathology (ret.), Forensic Medicine Section,
Pathology Department, Edinburgh University Medical School,
Edinburgh, UK*

Jean W Keeling

*Consultant Paediatric Pathologist (ret.), Royal Hospital for Sick Children,
Edinburgh, UK*

 **HODDER
ARNOLD**
PART OF HACHETTE LIVRE UK

First published in Great Britain in 2008 by
Hodder Arnold, an imprint of Hodder Education,
part of Hachette Livre UK, 338 Euston Road, London NW1 3BH

<http://www.hoddereducation.com>

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British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

ISBN-13 978 0 340 73157 4

1 2 3 4 5 6 7 8 9 10

Commissioning Editor: Philip Shaw
Project Editor: Amy Mulick
Production Controller: Karen Tate
Cover Design: Andrew Campling

Typeset in 9.5/12 Rotis Serif by Charon Tec Ltd [A Macmillan Company]
www.macmillansolutions.com
Printed and bound in [PLACE] by [PRINTER]

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DROWNING AND NEAR DROWNING

John Pearn

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INTRODUCTION

Drowning remains one of the most common causes of death in early childhood. In developed and affluent countries, after a child has passed the neonatal period, immersion incidents remain one of the three principal causes of death.^{1,2} In many states and communities within Europe, the USA, Canada and Australasia, drowning is the leading cause of unintentional death in children under the age of 5 years.³ This age group also exhibits the highest drowning mortality rate worldwide, except in Africa.⁴ Immersion fatalities rank as the second leading cause of accidental death for all older children and teenagers and this is the third leading preventable cause of death.⁵ In Australia, a water-orientated society, drowning has replaced motor vehicle accidents as the leading cause of all childhood deaths from injury.⁶ Autopsy diagnosis of the drowned child is challenging for the pathologist and is confronting for all who work proactively to reduce the incidence of immersion accidents.

Every case of drowning and near-drowning has potential forensic and legal implications. These apply not only to the work of pathologists, coroners, police officers and lawyers in the case of immersion fatalities, but also are inescapable as part of the clinical skills required by rescuers, bystanders, ambulance officers, paramedics and the emergency room team. In addition to the elucidation of the anatomicopathological features of drowning, and the establishment of precedents and causes of death, the forensic issues of immersion incidents may also include those of

child abuse or non-accidental injury, homicide, euthanasia and culpable neglect. The demonstration and interpretation of secondary trauma due to attempted cardiopulmonary resuscitation after immersion also depends upon meticulous autopsy technique.

Of all health professionals, pathologists develop the most pragmatic perspective of the serious threats to children's health, welfare and safety.⁷ Both the paediatric pathologist and the forensic pathologist have inescapable ethical roles in advocacy for the reduction of immersion accidents, a significant proportion of which are preventable.

THE CAUSES OF CHILDHOOD DROWNING: A PERSPECTIVE

Childhood drowning ranks high as a cause of child death, especially in the pre-school years (Table 18.1). The sites of the drowning incident include the family bath tub, private and public toilets, buckets and pails, private, family-owned swimming pools, public swimming pools, fish ponds and ornamental pools, building site trenches and drains, agricultural dams and tanks, residential and neighbourhood canals, lakes, creeks and rivers, boating marinas and the open sea(s) (Table 18.2). Children who drown in each of these sites have their own site-specific precedents and forensic concomitants.^{8,9}

The causes, sites, survival rates and modus operandi of immersion deaths all differ when child victims are compared

Table 18.1 Relative rank order (per cent) of traumatic and injury deaths in childhood (1–14 years)

Cause of death	Percentage
Drowning (accidental)	32
Motor vehicle occupant deaths	29
Pedestrian run downs	17
House/caravan fires	8
Homicide, child abuse	6
Falls, playground accidents, accidental strangulation	6
Other, e.g. poisoning, electrocution	2
Total	100

Data typical of tropical and temperate developed nations. Compiled from the Australian Institute of Health and Welfare⁶ and other sources.

Table 18.2 Relative rank order (per cent) of sites of drowning of children aged 0–5 years

Site	Percentage
Private swimming pools	64
Family bath tubs	16
Creeks	11
Dams, building trenches, sewers	5
Waterholes, fish ponds	4

Data typical of tropical and temperate developed nations. Compiled from the Brisbane Drowning Study^{17,43} and other sources.

with adult subjects. The common patterns of adult immersion incidents, involving alcohol, suicide¹⁰ and boating accidents, are rarely encountered in the case of childhood immersion victims. The common situation of difficulty with cadaver identification often encountered in long-immersed adult victims is very rare indeed; the identity of childhood victims is usually known and not open to question at the time of extraction from the water. Immersion times of childhood victims are measured in minutes rather than hours in more than 99 per cent of reported series.¹¹ The challenge of child immersion deaths to the forensic pathologist is that every case is individual and specific. Yet, however rare might be the circumstances surrounding an individual traumatic child death, diagnosis as to the cause of death and elucidation and reconstruction of its precedents are of the greatest importance.

In approaching a case of immersion death or near-death in childhood, the pathologist needs to adopt two approaches. The first is that of the usual detailed history-taking, followed by meticulous autopsy examination of the body with, in some instances, particular attention to post-mortem radiographic survey, blood analyses for drugs, chemical analyses of lung tissue, DNA extraction and storage, post-mortem photography and, rarely, bone marrow extraction for diatom examination (Table 18.3). The diagnosis of drowning is one of

the most difficult in forensic pathology.¹² In the case of child victims this difficulty is compounded when there may be no pathognomonic signs of drowning and where there may be no objective post-mortem signs of intentional injury, even when such is undoubtedly the case. Alveolar oedema, alveolar haemorrhages and emphysema aquosum are often the only histological features of drowning; even these may not be demonstrable in the case of an infant or child drowning when the duration of immersion is measured in minutes only.

The second tool, indispensable to the pathologist, is reference to the defined syndromic profiles of child drownings. Much recent research has built up patterns of quite distinct child immersion syndromes.¹³ Such form indispensable templates not only for the pathologist, but also for the investigating police and presiding coroner (Table 18.4). Childhood immersion fatalities do not form a spectrum of immersion incidents; rather they constitute subsets of quite distinct forensic syndromes that are unrelated to each other except by the end-point of drowning. Overall, 95 per cent of such cases are accidental (unintentional). In homicide cases, however, drowning is the method of killing in some 10–20 per cent (see Table 18.4). Reference to such immersion syndromes in the pre-autopsy analysis of any individual case is of great help to the pathologist in the choice of ancillary investigations (Table 18.3) and may be of the greatest help to family doctors, coroners and lawyers in subsequent proceedings.

Many childhood immersion fatalities are depressingly repetitive as many of these deaths are preventable. Nevertheless, all of those persons who are involved in the pre-mortuary chain – parents, siblings, neighbours, rescuers, bystanders, paramedics and police officers – are inevitably enmeshed in an intense personal and tragic incident. What happens to such individuals often depends on the determination of diagnostic truth, and such in turn depends on the pathologist's skill in recreating the events surrounding such immersion deaths. Because of the well-recognized, and indeed historic, difficulty in confirming death by drowning, there exists no greater challenge to the attending pathologist.

THE DROWNING MEDIUM

In at least 90 per cent of drowning fatalities, death is due to the inhalation of water into the alveoli, with hypoxaemia and subsequent brain hypoxia. The water in which children drown contains a case-specific mixture of inorganic substances, gases, dissolved organic matter and particulate matter. Particulate matter may include bacteria, fungi, diatoms, zooplankton and phytoplankton. Unlike the situation that is more frequently encountered in the forensic analysis of adult immersion victims, such water composition does not usually have clinical, forensic or legal overtones. Very rarely children drown in vessels filled with paint or fertilizer, or in agricultural, industrial or domestic chemicals.

Table 18.3 Forensic investigations apposite to immersion victims

Radiology	<p>Total body X-rays essential after immersion death</p> <p>Skeletal survey usually normal in private swimming pool drownings. Exclude cervical spine fracture-dislocations in deaths in public swimming pools, in sea or surf, in diving or suspected diving activity</p> <p>In bath tub drownings, skeletal survey excludes old fractures</p> <p>In unidentified/decomposed cadavers, dental pantograms are useful</p>
Histology	<p><i>Histology</i>: of lung, brain and heart is essential, sampling of other organs advisable</p> <p><i>Lung</i>: vascular congestion, oedema, alveolar macrophages, alveolar haemorrhage, emphysema aquosum;⁷³ foreign material, including stomach contents in larger airways or bronchioles</p> <p><i>Neck muscles</i>: intramuscular haemorrhages⁷⁴</p> <p><i>Brain</i>: vascular congestion, microhaemorrhages; immunohistochemical changes in hypoglossal nuclei²²</p> <p><i>Electron microscopy</i>: not required routinely</p>
Alcohol/drug assays	<p><i>Blood alcohol</i>: measure in all immersion victims over the age of 10 years; 60 per cent of adult male drownings have raised blood alcohol levels</p> <p>Antiepileptic drug levels when prescribed</p> <p>Screen for narcotics, psychotropic drugs, amphetamines and other drugs of abuse in all teenage immersion deaths</p> <p><i>Urine screen</i>: gas chromatography-mass spectrometry (GC-MS); detects prescribed medications, drugs of abuse, 'over-the-counter' drugs, dietary supplements⁷⁵</p> <p><i>Serum assay</i>: quantitative estimation of anticonvulsants, other prescribed medication and drugs of abuse using high-performance liquid chromatography assay (HPLC)⁷⁵</p>
DNA extraction	<p>Blood or tissue sampling for DNA identification not routinely required in most paediatric drownings; exceptions are suspected neonaticide, bath tub drownings, suspected child homicide and when maceration makes visual identification impossible</p>
Electrolytes	<p>Measurement of electrolytes rarely helpful</p> <p>Serum K may be increased due to haemolysis</p> <p>Serum Na may be elevated due to inhaled or swallowed sea water, or pre- or post-mortem dehydration</p> <p>Vitreous electrolytes are stable for some hours after death and may not reflect agonal serum changes</p>
Other biochemical studies	<p><i>Glucose</i>: not routine; hypoglycaemia may be related to alcoholic intoxication, exhaustion by physical activity or prolonged pre-death immersion in cold water;^{76,77} vitreous glucose is more stable</p> <p>Glucose in serum and vitreous should be measured in known diabetics</p> <p><i>Urinary myoglobin</i>: not routine, normal level < 50 ng/mL; can be very high in drowning but non-specific; elevated levels occur in fatal burns, heat stroke, asphyxia and drowning; may indicate exertional muscle activity or post-mortem change⁷⁸</p>
Diatoms	<p>Rarely needed; many different diatom genera and species have siliceous skeleton; femoral bone marrow sampled; tissue acid-digested or macerated, interpretation difficult, diatoms absorbed from the gastrointestinal tract pre-mortem; water from the putative drowning site essential for interpretation; concordance of diatom genera and species is only 65 per cent¹²</p> <p>Diatom analysis is helpful when: cadaver is badly decomposed; body is found on land but suspicion of prior drowning; body may have been put into the water after death^{12,79}</p>

Table 18.4 Relative rank order (per cent) of the modus of child homicide in the USA in children under the age of 5 years

Modus	Percentage
Head injury	45
Drowning	23
Non-drowning asphyxia	13
Body trauma	12
Other, e.g. neglect, poisoning	7

From ref. 9, with permission.

Fresh water

Fresh water contains variable amounts of organic material, dissolved salts and free and nascent gases. Most young children who drown do so in chlorinated, freshwater swimming pools; or in bath tubs with variable concentrations of dissolved soap or bath salts.¹⁴

The chemical affects of chlorine and soap in fresh water are not of consequence in the pathophysiology of the great majority of fatal immersions, and are certainly not of any practical significance in the pathophysiology of lung

syndromes in more than 95 per cent of survivors. Experimental animal studies have not demonstrated significant effects on the surface tension of lung surfactant when chlorinated water inhalation is compared with that of pure fresh water. However, any type of fresh water inhalation elevates the minimal surface tension of tracheal and lung surfaces very significantly when compared with the affects that follow salt water aspiration.

Sea water

Sea water contains a mixture of inorganic salts. Concentrations vary widely but the relative proportions of the different types of dissolved salts remain surprisingly constant. The total concentration of sea-water salts may change over relatively small distances, a phenomenon seen particularly in estuaries and even during tidal flow.¹¹ Salinity is defined as the total mass of dissolved solids (in grams) in one kilogram of water. Such is expressed either as parts per thousand (ppt) or in grams per kilogram (g/kg). In instances where children drown in inland seas, canals, rivers or delta regions (particularly during floods), the salinity of the inhaled water may be very low, approaching that of fresh water.

In organic sea water, a typical salt ion profile is:

- sodium, 10.5 g/kg;
- magnesium, 1.3 g/kg;
- calcium, 0.4 g/kg;
- chloride, 18.9 g/kg;
- sulphate, 2.6 g/kg.

Oceanic sea water thus typically contains 34.5 g/kg of dissolved salts, of which 29.5 g/kg is sodium chloride; this is equivalent to 2.9 per cent sodium chloride compared with 0.87 per cent sodium chloride that is the concentration in human plasma.

Irrespective of the salt content or osmolality of the inhaled water, during the drowning episode there is a one-way, massive transudation of water across the lung membranes into the pulmonary vasculature. Childhood drowning deaths are exclusively due to cerebral hypoxia followed by acute brain death. Any acute changes in osmolality, consequent upon salt concentration differences of the inhaled water, are not of forensic relevance. In survivors, because of rapid compensatory homeostatic changes – Starling's Law, the Bainbridge Reflex and renal clearance – such differences are not of practical relevance in the clinical management of near-drowned victims in the emergency room or intensive care ward. This is not to say that post-mortem electrolytes and osmolality should not be measured, as the issue continues to be a focus of legal debate in subsequent court hearings.

How much fluid is needed to drown a child remains unknown. Depth is no guide, as some infants drown in less than 20 cm of water in ornamental pools, garden fish ponds, pails or the family bath tub. Drug-intoxicated teenagers, patients with epilepsy and children with spinal or head

injuries (sometimes sustained during skylarking in the surrounds of swimming pools) can drown in very shallow water. In experimental mammals, as little as 1.0 mL/kg of fresh water instilled into the trachea causes gross pathophysiological responses in the lungs. Experimental studies, using dogs, have shown that drowning mammals may aspirate more than 22 mL/kg of water. The implication is that in the case of a typical childhood drowning (with a median age of approximately 2 years in most current series) a 13-kg child may aspirate as much as 300 mL of water. Such acute increase in blood volume is not greater than the capacity of the normal healthy child's heart to compensate for this potential fluid overload.

'Dry' drowning

There exists an historic debate about the proportion of cases of immersion accidents that are due to 'dry' drownings, in which laryngeal spasm is thought to be the primary cause of fatal hypoxia. Although laryngeal spasm occurs to some degree in every case of fluid inhalation, water enters the peripheral airways in at least 90 per cent of cases. In childhood, autopsy findings of 'dry drownings' are rare. Such evidence is supported also by clinical experience in the management of near-drowned survivors, where in every case there is evidence of water inhalation. In adult series, the frequency of 'dry drowning' has been variously estimated to occur in 10 per cent to 15 per cent of cases. However, a recent review of the original studies from which such conclusions have been historically drawn has indicated that such may be without firm foundation¹⁵ and that cardiac arrest, sustained coincidentally while the victim is in the water may be the true cause of death rather than asphyxia.

Despite this, there is persuasive experimental evidence to support the phenomenon of 'dry drowning'. In experimental drowning with diatom monitoring, using deliberate immersion deaths of aquatic mammals such as mink, muskrat and beaver, it has been shown that not all fully submerged animals inhale significant amounts of water into their lungs.¹⁶ When small amounts of water enter the larynx or trachea, immediate laryngeal spasm results due to an efferent vagal reflex. An immediate outpouring of thick mucus occurs, probably while the drowning victim is still conscious. Froth develops and in some cases a physical mucous plug forms. When such spasm relaxes preterminally, a significant amount of water is thus prevented from entering the trachea and lungs by the foam-froth plug, which acts as a physical barrier. In such cases, loss of consciousness is caused by anoxia or carbon dioxide narcosis. Death follows as a result of cerebral anoxia.

Water temperature

Almost all children who drown do so in water in a temperature range of 10–25°C. Water temperatures above 20°C do

not influence the brain-protecting diving reflex, but low temperatures augment it. The hypothermic, brain-sparing effects of near-drowning in very cold water are mediated through physical chilling of the body core and through an augmented diving reflex. In those situations when children drown in cold water, physical chilling of the body core is the result of not only the conduction and convection effects of cold water on the child's skin and through the involuntary inhalation of cold water, but also from swallowing relatively large amounts of cold water. All children extracted from the water in immersion incidents have a reduced body temperature, including those who respond to cardiopulmonary resuscitation and who may survive the incident. In boating accidents, in accidents involving falls through ice and in cold water accidents involving older children who can swim, immersion hypothermia may precede primary drowning asphyxia. Clouding of consciousness occurs in a drowning child when the core body temperature falls below 36°C; and consciousness is lost when core body temperature falls below 34°C.

Immersion asphyxia occurring other than in water

Rarely, children drown in non-water media such as paint, liquid fertilizer or industrial chemicals. Some children die after falling into wheat or grain silos, or are smothered in falls of earth or sand while playing in 'cubby houses', excavated 'Wendy' houses, or following the collapse of tunnels excavated into the sides of cliffs at the beach or beside rivers or creeks. In such cases the asphyxiating medium behaves as if it were a fluid. Inhaled paint or sand within the airways, for example, may be a dramatic macroscopic feature at autopsy; the foreign material may be demonstrated histologically (Table 18.3). However, in all such cases the mechanisms of anoxia are secondary to foreign substance inhalation. The mechanisms of oxygen exclusion (first with brain death and then with rapid somatic death) are identical to those encountered in cases of fatal water immersions.

THE PATHOPHYSIOLOGY OF DROWNING

A submerged infant or child holds his or her breath voluntarily until the 'break point' is reached. The 'break point' is determined by both hypercarbic and hypoxic drives. High arterial carbon dioxide levels combined with falling oxygen concentrations are synergistic. For example, the 'break point' occurs at PaCO_2 levels of below 55 mmHg if there is associated hypoxia; however, they may occur at PaO_2 levels of below 100 mmHg if the PaCO_2 exceeds 45 mmHg. In the case of older children, particularly those indulging in competitive or peer-demonstrative exhibitionism in swimming pools, the practice of pre-immersion hyperventilation is dangerous. Such underwater endurance games or dives

may alter the physiological setting of the breath-holding 'break point'. If the hypercarbic drive to breathe is lost, unconsciousness from cerebral hypoxia may occur before the hypoxia-induced 'break-point' is reached. This is the pathophysiological mechanism leading to drowning in teenagers or adults who, during snorkelling or free diving, attempt maximum endurance dives.¹¹

In all cases when the 'break point' is reached and the first involuntary inspiration is made, arterial hypoxaemia has already developed. Tissue hypoxia and acidosis have commenced. Involuntary gasping then occurs in a submerged subject, who may still be conscious. Glottal spasm occurs. Even before consciousness is lost, vomiting with aspiration of gastric contents may occur. Consciousness is lost within 3 minutes of involuntary submersion; and the electroencephalogram (EEG) becomes flat within 4.5 minutes. Breathing movements with fluid aspiration, and often the aspiration of sand, mud, gravel or vegetable matter, continues after the drowning victim has lost consciousness. Respiratory arrest follows. Dysrhythmias may follow and hypoperfusion with hypoxic blood leads to brain death. During the march of intra-immersion hypoxic events, intense autonomic, catecholamine-mediated blood redistribution occurs. The spleens of drowned victims are relatively bloodless, as one manifestation of the reflex constriction of splanchnic (including splenic) vessels.

The duration of brain hypoxia necessary to cause the death of an otherwise fit and healthy infant or child obviously remains unknown. Extensive research from the Brisbane Drowning Study,^{11,17} using a 'bracket method' and involving an analysis of hundreds of immersion fatalities and survivors, has indicated that (1) children who are immersed for 3 minutes or less are likely to survive an immersion incidents and (2) children are unlikely to respond to cardiopulmonary resuscitation if the immersion time is longer than 10 minutes in the most common water temperatures in which they drown (10–20°C).

The diving reflex

The brain-sparing diving reflex may be demonstrated in virtually all children, dramatically so in the case of neonates and young infants. The afferent arm of this reflex is the skin surface of the face supplied by the trigeminal nerve. The efferent arc involves the vagus nerve and the autonomic nerve supply to blood vessels of the skin and all internal body organs except those of the brain and heart. In the case of a submerged child, the diving reflex is manifest by rapid-onset bradycardia and the shunting of blood from cutaneous and splanchnic vascular beds to the cerebral and coronary circulations.¹⁸ Blood pressure starts to rise immediately. The diving reflex is augmented by catecholamine release and is probably inhibited by obtundant drugs such as alcohol. It has been estimated that the diving reflex may provide a drowning infant or young child with an extended

'window of salvage' of perhaps 30 seconds of immersion hypoxia.

Lung pathology

As soon as water enters the lungs, a chain of pathophysiological events occurs, as follows.

PERIPHERAL AIRWAY RESISTANCE INCREASES

Aspiration of even small amounts of water (1.0 mL/kg) is followed by pulmonary vasoconstriction, with immediate development of pulmonary hypertension due to parasympathetic reflexes. The composition of the inhaled water is important in this context. Vasoconstriction occurs, particularly following aspiration of fresh water into the mammalian lung; it occurs to a lesser extent in the case of sea water aspiration, but does not occur with aspiration of amniotic fluid.

LARYNGEAL SPASM

Laryngeal spasm follows, with an immediate outpouring of thick mucus, followed by froth development. The consequent degree of airway obstruction probably varies from subject to subject; the larynx relaxes preterminally.

REFLEX PULMONARY VASCULAR VASOCONSTRICTION

This phenomenon leads to immediate pulmonary hypertension. Intrapulmonary reflexes then cause shunting of blood through non-ventilated areas of the lungs. Such shunts, combined with surfactant loss or inactivation and consequent alveolar collapse, reduce mechanical compliance. Normally, intrapulmonary shunting involves no more than 18 per cent of the pulmonary vasculature; but within minutes of fresh water inhalation, some 75 per cent of the lung volume of such drowning victims manifests intrapulmonary shunting.

FLUID SHIFTS ACROSS ALVEOLAR MEMBRANES

A flux of inhaled water, irrespective of its osmolality, occurs across the alveolar epithelium, through the basement membrane and, finally, across the endothelial lining into the capillary lumen, where haemodilution occurs. This flux causes rapid and severe distortion of pulmonary ultrastructure with damage to both type I and type II pneumonocytes.^{19,20} Electron microscopic studies reveal endothelial changes of cell swelling, microvesical formation, cell detachment from the base of the membrane and cell destruction.

SURFACTANT CHANGES

Surfactant, primarily produced by type II pneumonocytes, is changed within minutes of water inhalation. Sea water and water containing sodium and chloride concentrations

that are approximately iso-osmolar (e.g. 0.87 per cent sodium chloride) with plasma, do not denature pulmonary surfactant but may dilute it or wash it out of the alveolar sacs. Fresh water, or inhaled fluid that is significantly hypo-osmolar, causes acute degradation of surfactant activity. Whether the lining surfactant is lost or denatured, the end result is the same and alveoli collapse.

FROTH FORMATION

Exudate outpouring from the laryngeal and tracheal membranes, surfactant washout from the alveolar sacs and disrupted alveolar membranes result in the formation of froth. The production of froth is characteristic, in variable degree, of a high proportion of the lungs and upper airways of drowned individuals. In some cases, it may be the only forensic manifestation that drowning has occurred. In cases of neonaticide, froth in the air passages is a valuable sign; when interpreted together with changes in the lungs it is indicative that a newly delivered fetus was born alive. The forensic evidence of post-immersion froth in the upper air passages is preserved if freezing has occurred, and can be demonstrated after warming even following freezing temperatures as low as -18°C .²¹ It is important to appreciate that any prolonged freezing of the body of a drowned subject will cause tissue distortion owing to ice crystal formation. This compromises the interpretation of subsequent histological examination.

Hypoxic cascade

In all immersion accidents the cause of death is ultimately irreversible cerebral anoxia. It is the end result of a hypoxic march of events,¹¹ any step of which may be influenced by the circumstances surrounding the immersion incident. This chain of cardiorespiratory events follows an inexorable sequence:

- voluntary apnoea;
- the diving reflex ensues, particularly in children;
- arterial hypoxaemia occurs;
- tachycardia and hypertension develop;
- tissue hypoxia ensues;
- tissue acidosis develops;
- inhalation with aspiration of water, followed by glottic spasm leading to a phase of secondary apnoea; consciousness is lost somewhere at this point of the pathophysiological sequence;
- involuntary respiratory movements occur, continuing under water until respiratory arrest occurs; the diaphragm may continue to contract after intercostal activity has ceased;
- hypotension occurs, with progressive loss of cerebral and coronary perfusion;
- dysrhythmias may develop, and in the case of children who drown the preterminal bradycardia may or may not be followed by ventricular fibrillation, before the inevitable asystole;

- cardiac arrest;
- brain death;
- somatic death.

Brain death after immersion accidents follows a primary state of altered neuronal metabolism. Research studies of changes in the hypoglossal nucleus (in the brainstem) indicate that compared with other quicker forms of asphyxia (e.g. hanging, strangulation and choking) pre-mortem damage to proteins such as the c-fos gene protein and the 72-kDa heatshock protein occur in this phase.²²

With increased percentages of the population trained in cardiopulmonary resuscitation (CPR) skills and the evolution of better ambulance services and more sophisticated intensive care units, recent years have seen a number of childhood immersion victims maintained on life support prior to their delayed death due to drowning. The forensic pathologist is involved in such cases and coronial autopsies are required in almost all jurisdictions. Examination of the brains of these children may demonstrate any or all of the signs of asphyxial brain death. Although cerebral oedema may develop in survivors, it is not a feature of autopsy studies in the drowned victim who dies within minutes of immersion. Besides petechial haemorrhages on the brain surface, there may be features of cerebral oedema, sometimes to the point of hemispheric swelling with resultant mass effect. Such massive oedema has not been reported in 'CPR survivors' who died within 24 hours after rescue. Delayed-death subjects, in whom there exists the legal imperative of coronial autopsy, may also show a wide constellation of lung changes. Such autopsy features range from relatively normal lungs, perihilar pulmonary oedema, generalized pulmonary oedema, pneumonia, collapse and consolidation, disruption of alveoli, alveolar haemorrhage, foreign inhaled particles in the airways, and signs of unilateral and bilateral pneumothorax. At post-mortem, such 'delayed drowning' lungs may manifest both macroscopic and microscopic features of the adult respiratory distress syndrome (ARDS).²³ In such cases there are often other features of pneumonia, due either to nosocomial infection or infection with waterborne bacteria or colonization by single-celled organisms. In the case of children who have survived with intensive care or ventilator support for hours or days following extraction from the water, there may be uncommon (indeed, exotic) micro-organisms found in pneumonia consolidates or lung abscesses. In the case of salt-water near-drownings, when death has occurred later in hospital, marine *Vibrio* bacteria or algae may be demonstrable.

FORENSIC IMMERSION SYNDROMES

From the perspective of the forensic pathologist, the site and circumstances of the immersion incident are of crucial importance in the reconstruction of events as these details

will form the substance of the final medicolegal report. Whereas the clinician is concerned, reactively in combating the clinical consequences of hypoxia, the pathologist is concerned with the recreation of the events that led to the primary immersion anoxic episode. In more than 95 per cent of childhood immersion incidents, unlike other forms of childhood trauma, the immersion incident is not witnessed. This fact, combined with historic difficulties of confirming death by drowning and the relative absence of specific forensic signs, places the pathologist in a position of great responsibility. For these reasons, there is an imperative to approach the pathological investigation against the background of all possible syndromic templates. There are at least 16 such age-site paediatric drowning syndromes, each with specific types of antecedent, different risks for the potential of unlawful child killing, different approaches to investigation and, ultimately, different stratagems for prevention. The importance of such syndromic definition is cognate to the generation of a clinical and forensic differential diagnosis when each new case is being assessed. Review of the child's entire past medical history is essential as a prelude to interpretation of the forensic autopsy results and indeed may modify the extent of technical investigation (Table 18.3) used in port-mortem analysis.

In many nations the crimes of neonaticide and infanticide are distinct from those of filicide, child homicide or unlawful child killing. Such jurisdictions recognize that the syndromes of neonaticide and infanticide have specific features not only in terms of aetiology, *modus operandi* and sociocultural implications, but also in prevention. There exists also the rare problem of false confessions to the drowning of children.²⁴ In these circumstances the recreating of events leading to the child's death is crucial to the legal protection of a parent or other party who may be psychiatrically disturbed.

In practice, the forensic examination of childhood immersion victims is straightforward. However, in every case judgement is required with respect to the choice of post-mortem ancillary tests and investigations. Most jurisdictions operate under conditions of scarce, and sometimes inadequate, resources. This applies particularly to pathologists or other medical examiners who are called upon to investigate childhood immersion deaths away from sophisticated forensic centres.²⁵ A small minority, less than 5 per cent of all childhood immersion accidents, have the potential for criminal overtones. However, with the increasing tendency for civil litigation, the pathologist may become enmeshed in highly complex and prolonged civil law suits, in which grieving and aggrieved parents seek compensation or damages from parties who are the site owners of water hazards in which children have drowned. For this reason, there is an increasing tendency for forensic pathologists to undertake tests and investigations that will leave no doubt as to the recreation of factual events that led to death in the water, or after failed attempts at post-rescue resuscitation.

Classification of drowning in children

There are two paradigms by which child drowning may be classified. The first of these uses the primary discriminator of intentionality, thus separating accidental drownings from the syndromes of unlawful child killing. The second approach is to classify drownings by site, each with its site-specific syndromic boundaries. Most medicolegal approaches to childhood immersion incidents use both approaches.

Child-killing immersion syndromes

NEONATICIDE

Neonaticide is defined variously, in different jurisdictions, as the killing of an infant in the first 24 hours of life or the killing of an infant in the first 4 weeks of life. In the forensic literature it is usually taken to mean the unlawful child killing of a subject delivered naturally and of sufficient developmental maturity to have been capable of independent survival, whose killing was perpetrated within the first 24 hours of life. Neonaticide by drowning is not rare, but it is, fortunately, decreasing in frequency in many Western societies. The syndrome is very specific and has been long recognized because of its sad sociofamilial overtones.²⁶ In general, neonaticide is in almost always perpetrated by the mother. In some legal jurisdictions, the crime of neonaticide, with its connotations of diminished responsibility, is only recognized as a specific crime if perpetrated by the mother.

The mothers are almost always young (95 per cent of cases), often teenagers. They are almost always single. Neonaticide by drowning usually occurs in the context of a concealed pregnancy and in the context of a concealed, solitary labour and delivery. The mothers are often members of ethnic minority groups, often in religious or language isolates living in Western society. Such families typically are those with religious or traditional cultural condemnation of premarital sexual relations. These tragic incidents are also sometimes encountered in white or black families, particularly in those of lower socioeconomic status, in which there is a very strict, male-dominated ethos in the micro-society in which the parturient mother is trapped.

In these circumstances it is not rare for a single teenage girl or young woman to conceal the pregnancy. At the time of the ensuing delivery and during labour, the victim will seek a private bathroom or public toilet in which to deliver her child secretly.²⁶ The mother adopts the least uncomfortable position for such solitary delivery. Under these circumstances, the neonate is often born into a toilet bowl or, less commonly, into a bath. In Western and oriental societies this usually occurs in a private or public toilet cubicle.²⁷

There is often doubt about the degree of intent of the deliberate taking of the baby's life, allowing for the diminished responsibility of a distressed, usually lonely and always ignorant primigravida. In many such instances, the

young single teenager, ignorant of physiology and without antenatal care, delivers herself of her infant. In the context of fear, pain and ignorance, a proportion of such mothers may not perceive the risk of immersion death. Having said this, neonaticide is the deliberative taking of the newborn's life and the related crimes of the deliberate exposure or abandonment of the newborn have been classic and not uncommon crimes known since antiquity. In this context, drowning is simply the *modus* of such unlawful child killing, the incidence of which varies, as it is always done, with the sociocultural mores and the economic circumstances of the parents of the neonate concerned.

Forensic autopsy of such infants needs to establish whether spontaneous breathing has occurred and whether the airways are patent, and whether asphyxia by water or other agents was the cause of death. As a proportion of such newly born infants are found dead in places such as public toilets, DNA extraction and storage is essential. The tracing, finding and identification of mothers is important in these distressing circumstances, as post-neonaticide identification of the biological father may have important forensic or legal implications. Such may occur if there is assault on putative fathers by the girl's family (particularly by her father or brothers) and in the rare cases when putative or biological fathers may be enjoined in the act of neonaticide itself.

INFANTICIDE

The crime of infanticide is the unlawful killing of a child under 1 year of age by its mother. The designated crime of infanticide has evolved as the judicial recognition that there is a subset of unlawful killings that are the result of diminished responsibility.

The deliberate killing of an infant, by a mother often disabled by psychosis, occurs not at birth but in the weeks or months following birth. Under these circumstances, drowning is, in one sense, a non-specific *modus*, as the means of ending the child's life.²⁸ Most such perpetrators are suffering from post-natal depression, with a smaller proportion afflicted with schizophrenia.²⁹ The intrafamily dynamics in cases of infanticide by immersion³⁰ differ from those encountered in cases of the deliberative, repeated, sub-fatal trauma, which is a feature of the crescendo child abuse syndrome that, of course, may ultimately lead to the death of the child concerned.

Post-natal depression is a dangerous syndrome for both infant and mother. When depressed mothers kill their infants, the proximity of the family bath tub or of washing machines, buckets or pails makes this cause of death well recognized. The syndrome of infanticide-suicide is well recognized by all forensic pathologists. Sometimes, a mother will kill one, several or all of her children before taking her own life.^{31,32} Infanticide by drowning may reveal, at forensic autopsy, skin features or lesions consequent upon the force exerted by the perpetrator to drown the struggling child. Some parents have attempted to drug their children before immersing them as the final act of killing.

The forensic pathologist has an important preventative role in infanticide, not of course in realized cases but as an advocate for increased surveillance and help to those mothers afflicted by psychosis (either by endogenous bipolar disorder or by schizophrenia) when the risk of infanticide may be high. Such risk remains high in subsequent pregnancies, and the syndrome of sequential infanticide, sometimes by drowning, is well recognized.

FILICIDE

Filicide is that crime in which the offender is a biological, adoptive or de facto parent. The method of killing is culture specific. In European, Asian, Canadian and Australasian societies the cause of such deaths are head injury, drowning or suffocation.³³ In the United States, homicidal asphyxia is less common in some regions, where gunshot murder is more frequently employed.³⁴

Mothers (60 per cent) kill their children more often than do fathers. Eighty per cent of such victims are between 1 and 5 years of age, with a median age of between 2 and 3 years.³⁵ Particular 'at risk' times for such immersion killings are in the early hours of the evening, particularly during weekends.³⁶

Site-specific immersion syndromes

BUCKET OR PAIL

A particularly difficult forensic immersion scenario is that which involves a child who has drowned in a bucket or pail.^{37,38} The majority of such incidents are undoubtedly accidental, but there remains a subset, of unknown proportion, in which attempted or realized infanticide or child homicide has occurred.

The age range of such victims is 9–20 months. Toddlers are at risk, but infants who are able to pull to stand, but cannot yet walk, are also at risk. The infant or toddler may become wedged in the bucket. No complete unselected (fatalities and non-fatalities) series for this type of accident has yet been published. A review of all published papers indicates that the mortality rate approaches 60 per cent and that the risk of post-accident neurological sequelae is high amongst survivors. A related and rare type of immersion involves those toddlers who climb up beside and fall into washing machines or washing tubs.

Buckets and pails are usually of 3–5 gallons (40–70 L) in capacity. The contents of the buckets are almost always water, soiled nappies, dirty mop water, bleach, detergent, soap or antiseptic.³⁸ These fluids have the potential to cause intense bronchospasm and life-threatening laryngeal spasm, irrespective of the immersion time. In survivors of such immersion incidents, there is always severe pneumonia and often systemic complications that require the most sophisticated management in the intensive care ward over subsequent days. In the case of fatalities, analysis of bucket or tub contents and of lung tissue forms an important

component of the chemical and toxicological approach that is so important in these accidents.

BATH TUB DROWNINGS

Immersion incidents in the family bath tub and in domestic spa pools have special implications for the forensic pathologist. From both the clinical and the forensic point of view there are eight defined syndromes of bath tub drowning and near-drowning (Table 18.5). Of these specific and definable bath tub or bath spa syndromes, accidental immersion is the most common in childhood. In adult series, suicides figure prominently.³⁹

A special challenge to both general and forensic pathologists, and also to clinicians, is the generation of a differential diagnosis in respect of causation to encompass the key presenting feature – the fact that the bath tub is the site of the immersion incident. If the clinician or pathologist does not consider the various syndromes that constitute such a forensic differential diagnosis (Table 18.5) then it is certain that lawyers in subsequent coronial, civil action or criminal courts will do so. The fact that perhaps 10 per cent of childhood bath tub drownings mask the tragic final result of crescendo child abuse necessitates full post-mortem X-ray skeletal survey in all such cases.

Almost all bath tub immersions involve fresh (tap) water, chlorinated to the standard 1 part per million (ppm). Diatom analysis plays no part in the interpretation of forensic bath tub analyses. By contrast, soap products are inhaled with water in many cases of accidental bath tub immersions involving infants and toddlers, unlike the situation in adult suicides³⁹ and some homicides⁴⁰ for which the bath tub is the site of death.

Bath salts are used in many children's baths, especially in the USA and Japan¹⁴ and in many affluent families of all nations. Bath salts contain fluorescein, which is highly sensitive to detection by high-performance liquid chromatography. Confirmation of fluorescein in lung tissue (and other tissues), in parallel with its demonstration in any residual bath tub water samples, may be helpful and specific. Its demonstration parallels the selected and rare use of diatom marrow demonstration following occasional fatal immersions in open water.

Accidental child drowning in bath tubs

Overall, 80–90 per cent of childhood bath tub drownings are accidental. The usual scenario of such accidents is the very human and universal situation in which a mother, tired at the end of the day, is attempting to coordinate the feeding and bathing of a large and vigorous family. As part of this, an infant who is in the bath tub becomes overlooked for several minutes before his or her well-being is checked.

The syndrome of accidental infant bath tub immersion is quite specific. Such fatalities and near-fatalities occur only, or virtually only, in working class, labouring and poorer families.⁴¹

Table 18.5 Site-syndromes of bath tub and spa pool drownings: forensic and clinical implications

Syndrome	Incidence	Notes
Accident	20 per 100 000 infants aged 0–11 months, annually 8 per 100 000 infants aged 12–23 months, annually	Poorer and working class families Large family size One-third are single-parent families ⁵⁰ High successful resuscitation rates (60 per cent) Child unsupervised due to sudden unexpected break in routine Parental dichotomy of care, each believing the other is caring for the infant 'Vulnerable periods' such as acute illness or marital discord
Child abuse	10–15 per cent of bath tub immersions estimated to be attempted or realized homicide	Families often known to child protection agencies Step-parents or de facto relationships increase risk Often other types abuse uncovered Some perpetrators 'draw back' after the child loses consciousness Sometimes precipitated by acute stress in a step-parent or de facto partner who is left alone with a toddler at a time of acute interpersonal discord
Child homicide	Rare – 12 per cent of all child homicides ¹⁰	Parent psychotically depressed or with low IQ Child homicide-suicide syndromes fall in this group High rate of realized death Only a small percentage survive
Bath tub epilepsy	Rare	Older children and young teenagers Victims may have uncontrolled epilepsy Children with a history of epilepsy who lock themselves in the bathroom for ablutions are particularly at risk
Euthanasia	Rare	A proportion of physically disabled toddlers and young children Often not concealed from police, altruistic intent
Bath tub drowning with cardiac pathology	Very rare; sudden cardiac death (all causes) in apparently normal children has a frequency of 1.2 per 100 000 patient-years	May be a history of cardiac abnormalities; especially those of bundle of His and right bundle branch block or long Q-T syndrome ⁵⁶ Although very rare, commonly raised as a defence against a charge of homicidal drowning or in civil claims for compensation after drowning

These accidents afflict infants and toddlers in a very defined, age-specific window of 8–18 months; the modal age of such accidents is 9–11 months.⁴² The mean number of siblings of victims of this type of immersion is greater than that of the population-matched average. The victims are usually the youngest or second-youngest child in the family – often the second-youngest, when there is a new baby claiming a significant part of the mother's attention. This peculiar vulnerability to accidents, to which children in higher birth ranks within the family are especially prone, is known to apply to other childhood accidents as well, especially accidental poisoning.⁴³

More than one-half of bath tub immersion incidents occur during a specific 'vulnerable period' when the family routine is suddenly or unexpectedly broken, such as that which occurs during acute sickness afflicting either the parents or children or in the context of marital strife.⁴¹ A typical scenario is that which involves a stressed mother, who is tired at the end of the day, attempting to cope, unaided, with the control, bathing and feeding of several high-spirited or fractious, but always vigorous, young children. The telephone rings, or an appliance breaks, or

someone calls unexpectedly at the door. The mother leaves two or three children, including an infant, in the family bath tub,^{44,45} leaving the youngest in the care of an older, but still pre-school, child – the older children may hop out of the bath when the mother is gone, leaving the infant alone.

Another factor in some infant bath tub drownings is the use of bath seats, which confer inappropriate assurance of safety,^{45,46} despite clear instruction from the manufacturers that the baby should not be left unsupervised.

Unlike other childhood drowning accidents that all show a preponderance of males, accidental bath tub immersions show an equal sex ratio. Of those infants and toddlers found unconscious in the family bath tub, some 60 per cent respond to CPR, with residual intact intellect and without neurological sequelae. This reflects the relatively short immersion times involved in such incidents.

Bathtub drownings and child abuse

All reviews of consecutive, unselected series of childhood bath tub immersions with detailed follow-up have revealed that some 10–25 per cent of such cases are in fact the result

of non-accidental injury.^{35,42,47} Forensic studies in Germany have shown that in 5–10 per cent of all child homicides in the under-5 age group, the *modus operandi* is drowning, usually in the bath tub.⁴⁸

The immersion assault is usually one such in a crescendo series of acts of child abuse perpetrated on the infant or toddler. Step-parents and *de facto* partners are almost exclusively the perpetrators. Some 'lose their nerve' during the assault and draw back and may summon help for resuscitation. A clue to the specific syndrome of child abuse by bath tub immersion may be that the child is older than the modal age for true accidental drowning in this site (9–11 months); or outside the typical 8–18 months age-specific window of vulnerability to bath tub immersion homicide. The median age of normal infants to be able to pull to stand is 9 months and the median age for walking in normal full-term infants is 13 months. Usually, children older than these ages can support their heads out of water in a bath tub, even if abandoned or left unattended for short periods of time. There should be a high index of forensic or coronial suspicion in all bath tub immersions involving toddlers older than 11 months, particularly if there is no history of developmental delay or epilepsy. The median depth of water in bath tub immersion incidents is approximately 20 cm.

Although deliberate hot water scalding by immersion in the bath tub is not uncommon in reported series of child abuse cases, the pathology of bath tub immersion incidents is primarily that of hypoxia and the two injuries are not reported coincidentally. It may be that the perpetrators do not wish to scald their own hands.

Bath tub drowning and child homicide

There exists the separate and distinct syndrome of child homicide, as a 'one-off' event, by bath tub drowning. As a single act, not in the context of ongoing child abuse, this assault is relatively uncommon. Syndromically, it almost always involves a parent afflicted by psychiatric illness or by low intellectual ability. Mothers are usually the perpetrators, have a psychiatric history and are living in disadvantaged socioeconomic environments. Mothers who kill their children prefer to strangle or drown their victims. Psychologists believe that in a large proportion of such cases the psychodynamics are those of surrogate suicide.⁴⁹ It is sometimes the *modus operandi* of the familiar and tragic 'child homicide-parent suicide' doublet. In this latter incident, tragically familiar to all forensic pathologists, one parent is almost always psychotically depressed, or in unremitting despair, and kills his or her child or several children and then immediately takes their own life. Survival rates for children involved in such incidents are low; less than 10 per cent survive this tragic scenario. Child homicide by drowning, in the context of sexual assault followed by homicide, always perpetrated by a stranger or non-biological relative, is rare. The mode of killing is almost always by physical

violence or strangulation, but the body is sometimes disposed of in a dam, creek or watercourse.

Infant homicide by bath tub drowning approaches the 'perfect crime' in that forensic skills usually cannot distinguish non-accidental submersion from accident. Two series of bath tub immersions have revealed that child homicide is a subset of the bath tub drowning syndrome – known only because of later, unsolicited confessions by the perpetrators.^{24,50}

Childhood bath tub immersion in epilepsy

A small proportion of children and teenagers drown, or almost drown, in the bath tub as a result of an epileptic seizure.⁵¹ Enquiry about a past history of epilepsy is important in both the clinical and forensic workups of all immersion accidents. There exist several specific issues relating to this syndrome.

It is very rare for children to drown in the sea or swimming pools as the result of in-water seizures.⁵² This applies even to children with uncontrolled epilepsy. The risks are significantly greater if there is a sub-therapeutic serum concentration of anticonvulsant drug present. The incidence of post-seizure bath tub fatality is less than 0.1 per cent of all childhood drownings.

There is a higher specific risk to epileptic children, especially teenagers with epilepsy, to fatal and near-fatal drownings in the family bath tub. All parents (and children) in families in whom uncontrolled epilepsy is present are warned not to take private plunge baths in the family bath tub, but rather to shower standing up. Several cases of flannels or 'washers' occluding the drainage plug, even during such 'stand-up' showering ablutions, have been reported in forensic series of fatal bathroom immersion accidents related to epilepsy.

Teenagers, being what they are, are often insistent on absolute privacy in the bathroom and insist on locking the bathroom door before taking a plunge bath or shower. If a seizure occurs, and the unconscious victim slides beneath the water, the chance of a successful resuscitation is small. Such cases are represented in all forensic series of childhood immersions. It is believed that the (misguided) practice of placing feverish infants into a hot bath – raising a high risk of febrile convulsion – may be the cause of immersion in a small proportion of cases of childhood bath tub fatalities.

Water impinging on the face, involving the sensory distribution of the trigeminal nerve, is the afferent trigger for the diving reflex.¹⁸ This leads to a complex series of dynamic cardiovascular changes, including increased vagal tone. There is some evidence that this may be one cause of 'bath epilepsy', initially described in the Indian medical literature but known to occur in all races.

Bath tub drowning and euthanasia

All series of unlawful child killings include cases of euthanasia.⁵³ They are usually perpetrated by a parent but

rarely by a grandparent or other close family member. One method of euthanasia is bath tub immersion. In the majority of such cases the child has a congenital disability, such as a neural tube defect, mental retardation, cerebral palsy or a chromosome abnormality. In occasional cases, the parent is psychotic, wrongly believing that a normal child is disabled or suffering when such in reality is not the case.⁴⁹

In instances of euthanasia by drowning, the motive is always (albeit tragically) an altruistic one. The parent believes that the child is suffering and that it would be kinder if the child was put out of his or her pain or misery, or that they could be helped from a tragic black or wicked world. There may be no attempt to conceal the crime. Some perpetrators proactively contact the police to report the incident.

Bath tub drowning and organic pathology

A final bath tub drowning syndrome is one in which pre-mortem pathology of the heart, recognized or unrecognized, is the cause of loss of consciousness during bathing. This syndrome is rare, but is included both for completeness and because the question commonly arises in the legal defence mounted by those charged with homicide by drowning. Sudden cardiac deaths in childhood and during adolescence are well known to forensic pathologists.⁵⁴ Myocarditis was demonstrated in 5 out of 22 cases of accidental drowning and underlines the need for full investigation of drowning deaths wherever they occur.⁵⁵ Importantly, the demonstration of pre-existing cardiac abnormalities in a drowned child may protect any innocent person on whom suspicion of culpable neglect has fallen. This applies not only to situations where child homicide is being considered in the differential diagnosis, but also applies to situations such as deaths in public swimming pools where lifeguards may be subject to criticism of neglect, sometimes of culpable neglect, in subsequent legal proceedings.

Congenital or acquired cardiac abnormalities are also the antecedent to drowning in some cases of older victims who drown in bathtubs,⁵⁶ swimming pools or open water.

Anomalies of the bundle of His, abnormalities of the right cardiac bundle branch and congenital abnormalities of the coronary arteries have all been reported in cases of teenage drowning, including bath tub drowning, in which toxicological tests for alcohol and illegal drugs have proved negative. In rare cases, genetic cardiomyopathies may be present.⁵⁷ The mechanism of such sudden and unexpected death during swimming or bath tub bathing is conjectural. One possibility is that the diving reflex (which follows facial immersion) induces cardiac dysrhythmia with heightened sensitivity, i.e. a priori abnormal hearts. It has also been suggested that cardiovascular damage may follow reduced venous return due to venous dilatation in hot water immersions; if this is superimposed on an 'at risk' heart then cardiac output may be insufficient to sustain consciousness.

Under normal circumstances, the cardiac output will be sufficient to return brain function to consciousness if an

individual temporarily collapses. However, if the individual is under water, secondary vagal stimulation from laryngeal irritation may compound the hypoxia that is already present. In this context, it is important to note that any drowning episode itself may provide an outpouring of catecholamines (the 'sympathetic storm'), which, with hypoxia, may result in microscopic changes to the myocardium, including myocyte contraction banding and focal myocyte hypereosinophilia.⁵⁸

SWIMMING POOL DROWNINGS

In most temperate and tropical countries of the developed world, the principal site of drowning in the childhood years is the backyard swimming pool. Salt-water immersions involving children are now less common than fresh-water immersions, even in littoral regions, for this reason. In the USA alone there are now over 12 million plastic wading pools and over 5 million surface swimming pools, of which an estimated 2 million are of the more dangerous, in-ground variety. Proportionate rates may be even higher in other countries, such as Australia and New Zealand. In many countries, pool drownings constitute 70 per cent or more of all consecutive unselected series of immersion deaths in childhood. In-ground pools cause 80 per cent of swimming pool fatalities. Motel, hotel, caravan and trailer park pools are a particular hazard in all reported series.⁵⁹ Even in countries such as Finland, as many near-drownings take place in swimming pools as occur in lakes, and twice as many in swimming pools as in the sea.

The current status of swimming pool drownings has been a feature of forensic series only since the early 1970s.⁴⁷ At that time, engineering technology and social affluence made private in-ground pools widely accessible. In many communities in many nations, one in five homes now has an in- or above-ground swimming pool filled with water at least throughout the warmer months of the year. Even in temperate climates, where winters may be freezing, pool-house ratios may be as high as 1:10. In the State of California, some 100 toddler drowning deaths continue to occur annually.

The age spectrum of such victims is between 12 and 40 months, with a modal peak between 18 and 24 months. The social class 'risk curve' is U-shaped, with deaths occurring disproportionately within richer families who, most commonly, have in-ground pools, and in poorer families where above-ground pools are often bought as an impulse purchase, installed and then poorly maintained. Above-ground pools are not as dangerous as in-ground pools. However, some children in the 18- to 36-month age range will climb a pool ladder, or will place a box or other object beside an elevated pool to gain access. Overall, 70 per cent of toddlers who drown do so in their own pools. Other 'at risk' pools are those of neighbours, motel, caravan or trailer park pools and the pools at homes of relatives whom children visit.

Toddlers and young children in this age-vulnerable window do not fear water. Many simply crawl into it, or step into such pools if no barrier is present. The Brisbane

Drowning Study⁴⁷ showed that often such victims were attracted to the water by a floating toy, rubber ring or ball, or by an object lying on the bottom of the pool. The following factors lead to higher survival rates following pool-side CPR: clothing (with its buoyancy), the diving reflex (preserved in infants and toddlers) and children found floating (with residual aeration) as opposed to those discovered on the bottom.

Toddlers virtually never drown in fenced pools with safety standard-approved self-latching gates with high, hidden locks. Intense advocacy, often supported by pathologists, to introduce policed, safety legislation to protect toddlers from such water hazards has been unsuccessful in many communities. Most toddlers who drown in such pools do so within 30 m of their own home. Immersion times are almost always under 20 minutes. Successful resuscitation rates for consecutive, unselected series of all such swimming pool immersion accidents approach 60 per cent and rise to 70 per cent if a trained first aider happens, coincidentally, to be involved in the attempted resuscitation. Survivors do well, and some 97 per cent of children who survive this near-drowning syndrome function normally. Some 30 per cent of such survivors have wide sub-scale disparities on formal psychometric testing but do not manifest clinical neurological signs.

Autopsy findings of such children are typically those of a completely fit and well toddler who is alive at one moment and dead 10 minutes later. In such cases there may be minimal anatomical changes in the lungs. The body often shows post-mortem signs of CPR trauma, including fractured ribs, contused pericardium or injection needle marks from the frantic use of cardiostimulant drugs by ambulance officers, paramedics, firemen (in the USA) or physicians.

PUBLIC SWIMMING POOL DROWNINGS

A small proportion of children, almost always in the age range of 3–18 years, drown in public access swimming pools or aquatic parks. One US study draws attention to an excess of deaths in this situation to black, adolescent males.⁶⁰ Such individuals are typically found on the bottom of the pool by another casual swimmer. Very commonly, such drownings are followed by major medicolegal, civil, insurance and regulatory consequences. A high proportion of such drownings becomes the focus of prolonged court cases, often involving claims for large compensatory sums of money; commercial pool owners, lifeguards, paramedics, emergency room physicians and forensic pathologists may all become enmeshed in complex discussions about pathophysiology and the differential diagnosis of the causes of drowning in general.

The majority of such cases are simply due to the fact that individuals, usually poor swimmers, cannot stay afloat and so they inhale and the 'drowning chain' ensues. Swimming lessons and, perhaps, optimistic evaluation of swimming ability, may engender a false sense of security amongst

parents. They are no substitutes for parental vigilance and close supervision when children are in the water.^{61,62} A small proportion of such cases involve children who have been skylarking in the pool surrounds, fall and hit their heads or become winded and cannot extricate themselves when they become submerged. Another subgroup is probably secondary to cardiac abnormalities, often congenital in nature but hitherto unrecognized; this group includes those with congenital coronary artery or valvular abnormalities or those with hitherto unrecognized dysrhythmias, with mechanisms similar to those described in the case of bathroom immersions. Some rare cases are consequent upon cervical spine injuries following diving accidents. A very small sub-group are consequent upon epileptic seizures in the water. In this latter context, however, it must be said that swimming pool drownings due to proven epileptic seizures are extremely rare. This is not to say that children do not have epileptic seizures in the water but, in practice, most are recognized and the victim is extracted without significant hypoxia and without any subsequent post-hypoxic neurological defects.⁵³ Another subset comprises those young teenagers who have taken alcohol or drugs, and who lose coordination in the water, or sometimes who are illegally or clandestinely swimming in pools, often as members of group 'larks', sometimes involving 'skinny dipping' (nude swimming) at night. Another subset consists of children performing the dangerously underrated practice of hyperventilating before diving and underwater swimming in such public pools.

Because of the extended differential diagnosis that is inescapable in such cases, often dissected in meticulous detail in subsequent court proceedings, it is absolutely essential that the widest array of appropriate post-mortem investigations be undertaken. This includes radiographic studies (especially of the skull, chest and spine), alcohol and drug assays and meticulous forensic autopsy techniques in the examination of heart, lungs and brain (Table 18.3). In practice, it is uncommon for such cases to result in positive findings in any of these investigations, but the careers, reputation and professional security of many individuals who are involved in the rescue, the attempted resuscitation and the management chain may well be dependent on the pathologist's findings and defended opinion. Perhaps most importantly of all, 'closure' of the grieving process by parents and loved ones is facilitated by the forensic pathologist's confident recreation of the events that have led to post-immersion somatic death.

RIVERS, CREEKS AND LAKES

Children occasionally drown in rivers and creeks and in lakes.⁶³ Those who do are almost always (90 per cent) boys, and the modal age falls in the age window of between 8 and 12 years. There is often an element of disobedience involved in such cases, when children are swimming far from supervision. The typical scenario is when a boy or male teenager experiences difficulties in the water and his

friends find that they are unable to rescue him and run for help. Because of the distances involved, resuscitation attempts are unsuccessful in more than 90 per cent of cases. Estimated immersion times are relatively long and often exceed an hour or more before the body is extracted from the water. The forensic autopsy often reveals gravel, sand or aquatic flora in the air passages.

DRAINS, TRENCHES AND SEWERS

Children who drown in drains, trenches and sewers are almost always boys, and sometimes more than one victim is drowned in the same episode. The victims are often playing or swimming in forbidden areas. Often, extraction from the water is difficult and bodies may be wedged in outlet pipes or municipal watercourses. A series of such drownings always include that subset of children who are playing in fast-moving and dangerous waterways during floods. Under such circumstances the novelty of the situation may mask the threat of immersion and the bodies of the victims may never be recovered. Other are found wedged in or entrapped in pipes or outlet drains or under submerged trees.

SEA DROWNING

Many nations have high shoreline-area ratios, with a population who are sea-oriented from infancy. In such regions, children grow up in an environment in which respect for the ethos of both water safety and water danger is a natural part of culture and folklore. Under these circumstances, sea drownings involving toddlers are relatively uncommon.⁶⁴ Older children are particularly at risk.

Child victims of sea drownings are found disproportionately among immigrants, tourists or other ethnic subgroups.^{17,65} The children and their parents may not be aware of the threat of the sea or surf. Occasionally, young teenagers drown during sailing excursions but, in general, boating and the use of surfboards, in current practice, are low drowning threats to children. Childhood drownings in the sea occur almost always during daylight hours and, as a manifestation of the recreational use of the sea, most often occur during weekends or holidays. Childhood salt-water immersion rates are unaffected by tidal state. Most sea and surfing beaches are separated by road, dune strip and a beach from residential houses. The result of this is that it is very unusual indeed for toddlers or preschool children to drown in the open sea; the modal age for this type of sea drownings is 8 years. The phenomenon of 'secondary drowning' is most often identified after salt-water drownings. In this latter syndrome an individual may be extracted, pulseless, from the water and may respond well to cardiopulmonary resuscitation, only to manifest life-threatening deterioration hours later due to washout or denaturation changes in pulmonary surfactant.

Children are sometimes envenomed by jellyfish or poisonous fishes while swimming.⁶⁶ Under such circumstances, as in the case of adults, there is a very serious risk of

secondary drowning consequent upon pain, panic and the ensuing incoordination even amongst proficient swimmers. The victims of stonefish envenomation, which are commonly encountered throughout the Indo-Pacific littoral in both tropical and temperate waters, often become maniacal with pain. If this occurs during snorkelling, scuba-diving or reef walking, drowning is an ever-present threat. A search for, and identification of, barbs or other foreign material from the venom apparatus is important in such cases. Severe envenomation by cubomedusans can cause death by direct envenomation while the victim is still in the water, or from a combination of envenomation and drowning. Box jellyfishes (sometimes called 'sea wasps') are amongst the world's most venomous creatures and many of the recorded victims of such deaths, a disproportionate number of whom are children, occur before the victim can be extricated from the water. In the forensic examination of such victims, a strip of adhesive tape applied to areas of the skin thought to be affected and then examined under the microscope may reveal not only the characteristic nematocysts, but also will enable both genus and species identification to be made.

The forensic autopsy of salt-water drowned victims usually shows no specific distinguishing features if the body is retrieved within several hours after the drowning episode. As in adults, the bodies of long-immersed child victims may show secondary changes due to crustacean or piscine post-mortem damage. In such cases forensic identification may be difficult and dental X-rays, post-mortem fingerprinting or DNA extraction and analysis are essential.

AFTERMATH

Only a minority of immersion incidents result in fatalities.^{67,68} An understanding of the pathophysiology of the immersion sequence leading to somatic death, taken in conjunction with the documentation of post-mortem changes, will mean that both more efficient prevention and better cardiopulmonary resuscitation will be possible in the future.

The documentation and subsequent compilation of childhood immersion statistics is very important from the point of view of future prevention. In this context, case finding of immersion fatalities undertaken for epidemiological research is compromised because of the many different causes and syndromes of drowning in childhood. As many as 1 in 10 cases of childhood immersions may not be retrieved for analysis. For example, some are coded as motor vehicle injuries in those cases when vehicles have crashed into the water.⁶⁹ Multiple-cause coding is essential if a community's or nation's statistics are to be fully exploited in the context of injury prevention.⁷⁰

The pathologist's professional and ethical responsibility is to the dead child and to the determination of the circumstances of that death. The evidential value of such autopsy findings, however difficult may be their interpretation in the current stage of knowledge, is of the greatest importance. Ultimately, the integrity of not only the professions of

medicine and of law depends upon such a forensic service, but also that of society. The deliberative killing or preventable death of a child defines, in part, the society in which such tragedies occur. From the professional point of view, the pathologist also has both a professional and an ethical responsibility to any living siblings of children who have died from immersion, whether accidental or not.

Much remains to be achieved in fostering closer collaboration between clinicians caring for the survivors of near-drowning incidents and the pathologists who investigate fatal immersions.^{71,72} Paediatric and forensic pathologists have an important role to play in preventative medicine and in promoting advocacy for public health stratagems that relate, in particular, to home and water safety in communities in which drownings are common.

A child's death from drowning is, in one sense, from the family's point of view, the beginning of a new era. The role of the pathologist is a crucial one in helping parents in the immediate aftermath of death. To be able to recreate exactly what has happened often brings long-term resolution to the aftermath of a child's drowning, which is always a tragedy.

ACKNOWLEDGEMENT

I thank Dr Terry Sinton, a senior forensic pathologist of the John Tonge Centre, Queensland Health Pathology Services, Brisbane, Australia, for much encouragement.

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CONTRIBUTORS

Denis R Benjamin
Department of Laboratories
Cook Children's Medical Center
Fort Worth, TX, USA

Jem Berry
Professor in Paediatric Pathology (ret.)
Directorate of Pathology
St Michael's Hospital
Bristol, UK

Anthony Busuttill
Regius Professor of Forensic Pathology (ret.)
Forensic Medicine Section
Pathology Department
Edinburgh University Medical School
Edinburgh, UK

Helen Carty
Dept of Radiology
Alder Hey Children's Hospital
Liverpool, UK

Alex M Graham
Division of Pathology (Forensic Medicine)
School of Molecular and Clinical Medicine
College of Medicine and Veterinary Medicine
University of Edinburgh
Edinburgh, UK

Helen Hammond
Consultant Paediatrician (Community)
Dept of Community Child Health
St John's Hospital
Livingston, UK

David J Harrison
Director
Edinburgh Cancer Research Centre
The University of Edinburgh
Edinburgh, UK

Jean W Keeling
Consultant Paediatric Pathologist (ret.)
Royal Hospital for Sick Children
Edinburgh, UK

TY Milly Lo
Clinical Research Fellow
Department of Child Life and Health
The University of Edinburgh
Edinburgh, UK

Patrice Mangin
Institut Universitaire de Medicine Legale
Lausanne, Switzerland

Robert A Minns
Dept of Child Life and Health
The University of Edinburgh
Edinburgh, UK

Jacqueline YQ Mok
Consultant Paediatrician
Community Child Health Services
Edinburgh Sick Children's NHS Trust
Edinburgh, UK

GH Moody
The Faculty of Dental Surgery
The Royal College of Surgeons of Edinburgh
Edinburgh, UK

John Pearn
Professor of Paediatrics and Child Health
The University of Queensland
Royal Children's Hospital
Herston, Queensland, Australia

Waney Squier
Dept of Neuropathology
Radcliffe Infirmary
Oxford, UK

Angela Thomas
Dept of Haematology
Royal Hospital for Sick Children
Edinburgh, UK

Dick Variend
Dept of Histopathology
The Children's Hospital
Sheffield, UK

David Whittaker
Emeritus Professor in Forensic Dentistry
University of Cardiff
Cardiff, UK

Harry Willshaw
Consultant Paediatric Ophthalmologist
The Birmingham Children's Hospital
Birmingham, UK