have medico-legal connotations if an injury (which includes a surgical procedure) is performed on someone who has a haemorrhagic diathesis either from natural disease, or from therapeutic anticoagulant treatment, such as heparin or warfarin.

Delayed bleeding may be seen in a number of conditions. In trauma, especially traffic accidents, organs, such as the liver, spleen or (sometimes) lung, may be injured within their capsules or covering membranes, which initially remain intact. A good example is a subcapsular haematoma of the liver, which may be large and grow even larger as continued bleeding strips more capsule from the parenchymal surface. Eventually, the blister may rupture and the now unrestrained bleeding area can pour into the peritoneal cavity. Trauma can also weaken the wall of an artery or vein, leading to a false aneurysm, which can later rupture. An arteriovenous fistula can also form and later burst.

Infections can also develop in trauma sites and involve vessels in the vicinity, so that an abscess or cellulitis can secondarily lead to severe haemorrhage when the vessel wall is eroded. This is rare except among poorly treated accident or battle casualties, as are mycotic aneurysms that result from infected emboli impacting in a branch of an artery and causing local septic necrosis.

It is sometimes difficult to know how much of a haemorrhage found at autopsy may be accounted for by post-mortem bleeding. There is little doubt that the volume may increase after death, but, except in serous cavities, such as the pleura and peritoneum, or externally from the body surface, in most cases this is a small proportion of that which leaked under arterial pressure during life, due to the tissue pressures opposing passive bleeding.

However, a haemothorax from a ruptured aorta may amount to several litres and much of this may be in the form of a large shaped clot. A clot can form post-mortem, so its presence cannot be taken as an index of *in vivo* formation, but the source of the bleeding will usually be obvious and any post-mortem addition will not affect the interpretation. Copious external bleeding can continue after death, especially from the scalp, particularly if the head is dependent after death.

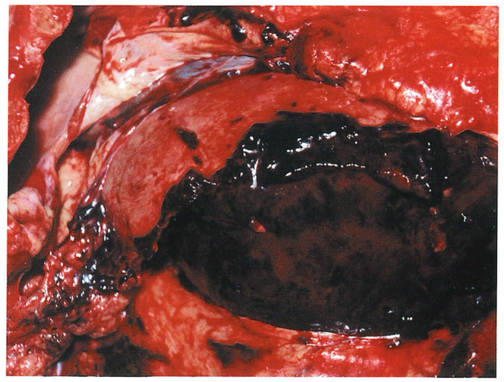

FIGURE 13.1 *Massive intra-abdominal bleeding from a subcapsular haematoma of the liver due to blunt abdominal trauma.*

INFECTION

Infection used to be so common after open wounds that it was the norm rather than the exception. Prior to the introduction of sulphonamides and antibiotics, many criminally inflicted wounds, which in themselves were not a danger to life, became fatally infected so that an assault became a homicide. This illustrates the fallacy of comparing murder rates in the last century with today, as the survival rate because of rapidly available ambulance and resuscitation services, blood transfusion, emergency operations and antibiotics is vastly greater now than in former times, when even a trivial injury was often fatal.

The types of post-traumatic infection are legion and vary greatly from country to country. Purulent wound infection from Gram-positive cocci, Gram-negative bacilli, anaerobes, such as *Clostridium perfringens*, and other more common organisms, is the most frequent, but in some countries tetanus and anthrax are common dangers. The whole matter is one of clinical microbiology, and the main forensic relevance is to prove a chain of causation between the original injury and a death from intercurrent infection. There may be medico-legal issues involved, such as failure to give or delay in giving antibiotic cover, which can have both civil and criminal legal consequences. A criminal assault that ends in death because of a neglected infection does not exonerate the perpetrator from all responsibility, even though there has been a *novus actus interveniens* in the form of defective medical treatment.

PULMONARY EMBOLISM

This is a most important topic in forensic pathology, as the medico-legal implications of a fatal pulmonary embolus are common and profound. Pulmonary embolism is the most underdiagnosed cause of death where no autopsy is performed; it has been estimated that, in the USA – and probably elsewhere – less than half of fatal pulmonary emboli are recognized clinically.

As with infection, an originally non-lethal injury may end in death because of venous thrombosis and pulmonary embolism, making what might be a simple accident or a

common assault into a grave legal issue. The victims of many forms of trauma are at risk from pulmonary embolism because:

- Tissue trauma increases the coagulability of the blood for several weeks, the peak being between one and two weeks.
- Injury to the tissues, especially the legs or pelvic region, may cause local venous thrombosis in the contused muscles or around fractured bones.
- The injury may confine the victim to bed, either because of general shock and debility (especially in old people) or because the trauma itself necessitates recumbency, as in head injuries, severe generalized trauma or injury affecting the legs. In either case, recumbency leads to pressure on the calves and immobility causes reduced venous return and stasis because of lessened muscular massage of the leg veins. The common result is thrombosis of the deep veins of the legs, which can extend proximally into the popliteal and femoral vessels, forming a dangerous source of venous thromboemboli. Small emboli may break off and impact in more peripheral branches of the pulmonary arteries, sometimes causing pulmonary infarcts that may be precursors of a massive embolus that impacts in the major lung vessels and causes rapid death.

At autopsy, such large emboli are readily visible and can usually be easily distinguished from post-mortem clot. The latter is dark red, soft and jelly-like, with a shiny, glistening surface. It is often separated into 'chicken-fat' plasma clot and dark red-cell clot by sedimentation after death. When pulled out of the vessels it forms a cast of the branches, albeit shrunken by clot retraction. It is less evident in peripheral branches and, when the lung is sliced post-mortem, clot does not pour out of cut small vessels.

Conversely, ante-mortem embolus (especially if a number of days old) is firm, though brittle and has a dull, matt, striated surface from fibrin lamination. Older thrombus tends to be greyish-red and varies in colour from place to place. Although it may appear to be a cast of the large vessel in which it is impacted, it may often be unravelled to form a long length that obviously originated in a leg vein. Side branches, or the stumps thereof, may be seen that do not correspond to the branches of the pulmonary artery in which they lie.

Post-mortem clot may be adherent to the ante-mortem embolus and sometimes forms a sheath around it, so that the true nature is obscured unless a careful examination is made. On cutting the lung with a knife, ante-mortem emboli may be seen in the more peripheral vessels, often standing up slightly 'proud' above the surface, like toothpaste coming from a tube.

The importance of the differentiation between ante-mortem emboli and post-mortem clot is emphasized, as the legal issues hanging upon the unequivocal diagnosis may be very important. Histological confirmation of an ante-mortem origin must be made if there is any doubt. Pulmonary infarction does not occur from fatal massive pulmonary embolism, as death is too rapid. There may be infarcts present in the lungs but these must be caused by previous smaller emboli, at least a day earlier and probably much longer.

Medico-legal aspects of pulmonary embolism

Pulmonary embolism is the most underdiagnosed condition in British death certification, frequently being unsuspected as the cause of death by clinicians. Several investigations into the medico-legal aspects have been made (Knight 1966; Knight and Zaini 1980; Zaini 1981) and the peak incidence at about 2 weeks after trauma confirmed. In Knight's survey, more than three-quarters of the victims had predisposing factors such as injury, surgical operation or immobility in bed, but the remaining 20 per cent were ambulant and apparently healthy. This has important medico-legal implications because, if fatal pulmonary embolism can strike an appreciable proportion of the population who have not suffered one of the recognized predisposing factors, then the cause–effect relationship after trauma is weakened. If the standard of proof in criminal trials must be 'beyond reasonable doubt', then the fact that up to 20 per cent of pulmonary embolism deaths have not followed trauma or immobility must surely remove the cause–effect relationship from near-certainty to mere probability, which is sufficient for a civil decision, but not for a criminal conviction. This is a legal matter for the judge, however, who may or may not let the matter go to the jury – and if it does, for the jury to decide. There is marked variation in these decisions from case to case.

After the lung appearances have been examined and pulmonary embolism confirmed, the source of the embolus must be sought. In almost all cases this will be found in the vessels draining into the femoral veins, though rarely pelvic vessels are involved (usually in relation to pregnancy or abortion). Here pelvic veins may be thrombosed, with extensions into the iliac system and exceptionally into the inferior vena cava. An even more rare source is from jugular thrombosis, sometimes seen as extensions of intracranial venous sinus thrombosis. Axillary and subclavian vein thrombosis is equally unusual, the legs accounting for the vast majority of emboli.

In the usual leg vein thrombosis, various autopsy techniques are available to seek the site of obstruction. Extensive dissection is favoured by some, in which the femoral vein is

exposed through a skin incision, this being continued distally as far as necessary to find the residual thrombosis. Of course, after a massive pulmonary embolus, by definition a large part of the source thrombus has been detached and therefore the pathologist has to search further distally to find the remnants. This makes dissection an extensive and disfiguring process, so alternative techniques can be used.

Zaini found that many thrombi begin far distally, even in the dorsum of the foot. He used a flexible wire with a blunt terminal knob (a Bowden cable from a bicycle brake) inserted down the femoral vein until it was arrested, then cut down from the skin at that point to examine the peripheral veins. Alternatively, transverse or longitudinal incisions can be made into the calf of the leg to examine the deep veins. The soleus and gastrocnemius muscles are transected to view their contained veins, but often the thrombus is found in the interosseous veins between tibia and fibula. If ageing of the thrombus is attempted histologically, then it should not be expressed from the vein, but the vein should be taken out with adjacent muscle, as it is the junction between thrombus and vein wall that offers the most information about the maturity of the thrombus.

Dating of pulmonary emboli and deep vein thrombi

As discussed above, it can be a matter of considerable medico-legal importance to know if a pulmonary embolus arose prior to, or subsequent to, some traumatic event. A major difficulty is that the embolus may be the most recent addition to an extending venous thrombosis that is considerably older.

It is also difficult to use histological criteria to date the free embolus from the lungs, as it is the thromboendothelial junction that provides the most information. The best method, therefore, is to examine the residual thrombus, almost always in the leg veins, to see if the oldest part could have formed as far back in time as the suspected traumatic event. For this, the vein wall with the contained thrombus is required. A segment of thrombosed vein, if necessary with adjacent muscle, should be dissected out of the leg. The presence of thrombus will have been confirmed prior to removal by transverse cuts across the calf or thigh muscles containing the veins. Sometimes the original site of thrombosis may be as far distal as the dorsum of the foot.

The thrombus-containing vein is processed in the usual way and subjected to various histological stains. Though accuracy about dating is impossible, the following is a useful scheme to provide at least an approximate idea of the duration of thrombosis in the section of vein under study – remembering always that other segments or other veins may have thrombi of different dates.

- Platelet and red-cell appearances give no useful information. Red cells begin to haemolyse between 24 and 48 hours to form amorphous masses, but many intact red cells survive for weeks.
- Using phosphotungstic acid-haematoxylin stain (PTAH), fibrin can be seen as purplish strands on the first day, but they aggregate into small masses with a meshwork of thicker strands and sheets by 4 days. After 2 weeks, the fibrin becomes more deeply purple stained, but begins to be absorbed by about the twenty-fifth day. Using Martius Scarlet Blue stain (MSB), the early pink fibrin strands become fringed by scarlet in about a week.
- Endothelial proliferation is most useful in the first week, as buds begin to arise from the vessel wall about the second day and proliferate during the first week. Clefts lined by endothelium are seen around the periphery of the thrombus against the vein wall. Artefactual contraction caused by fixation shrinkage must be excluded by seeking endothelial nuclei. These endothelial buds anchor the thrombus to the vein wall, and represent the first stage of healing and recanalization. They are usually noticeable by about the fourth day when they begin growing into the fibrin mass and breaking it up into compartments.
- Collagen fibres do not appear for about 5–10 days, often much later. Fibroblasts may be seen as early as 2 or 3 days, but tend to appear towards the end of the first week and reach a maximum at 2 or 3 weeks, reaching a maximum at about 4 weeks. Elastic fibres appear late, not before 28 days and often much later. They reach their maximum density in about 2 months, mainly in the walls of recanalizing vessels.
- Haemosiderin, blue granules demonstrated by Perl's reaction, may be seen by the end of the first week and reach a maximum in 3 weeks. It does not seem to be present as early in thrombi as in extravascular haemorrhages, such as bruising or meningeal bleeding, where it can be seen in 2 or 3 days.
- Capillaries begin to appear on the second day as endothelial buds, but do not contain red cells until about 2 weeks. Over the next 3 months, substantial canalization occurs by widening and merging of these channels. The full lumen may be restored within 6–12 months, but endothelial thickening and haemosiderin deposits in the vein wall may form permanent evidence of a former thrombus.
- Leucocytes, both polymorph and mononuclear, are inconsistent markers; sometimes they do not appear at all. Polymorphs may be seen within the first day – sometimes in profusion – but they vanish rapidly, often by the next day when mononuclears take their place.

- Covering of the thrombus surface by endothelium is rapid and may begin on the first day and be complete within a few days. Various authors have given 24–72 hours as the time required. Naturally, the size of the thrombus surface is a variable factor. Also, only sections taken where the thrombus does not fully fill the vein lumen will provide an opportunity for observing the endothelial covering.

FAT AND BONE MARROW EMBOLISM

Another important sequel to trauma – fat embolism – is the subject of considerable controversy about the source of the lipoid; this does not, however, detract from the autopsy significance of its detection.

A great deal has been written about the pathophysiology of fat embolism and it is now evident that it is not just a simple extrusion of marrow or adipose tissue material by mechanical trauma. The work of Sevitt (1962), Bergentz (1961), Edland (1971), Ellis and Watson (1968), Buchanan and Mason (1982), and many others must be studied for detailed accounts of the suggested pathogenesis.

Wherever the fat comes from, embolism is most often seen after injury to bone or fatty tissue. In simplistic terms, where skeletal structures containing fatty marrow are damaged or where subcutaneous fat is compressed or lacerated, fat globules commonly appear in the pulmonary capillaries – and where they are numerous they somehow leak through the lungs into the systemic circulation where they can cause severe disability or death from impaction in vital organs, such as brain, kidney or myocardium. Not only fat, but cellular haematopoietic tissue from bone marrow, can be liberated into the venous system and reach the lungs.

The clinical manifestations of fat embolism depend on the volume of fat reaching the lungs. If substantial, ventilatory problems can ensue because of vascular obstruction and pulmonary oedema. The most dramatic symptoms occur, however, with systemic fat embolism when globules reach the brain and cause a range of neurological abnormalities, usually coma and death from brainstem involvement.

There is usually a delay between trauma and cerebral fat embolism while fat builds up in the lungs, so that a 'lucid interval' occurs, which may be confused clinically with the development of an extradural or subdural haemorrhage. Sevitt stated that of patients with multiple bone fractures, no fewer than 45 per cent had pulmonary fat emboli and 14 per cent had cerebral embolism.

Fat embolism is also associated with burns, barotrauma, soft tissue injury, osteomyelitis, diabetes, surgical operations on fatty tissues (especially mastectomy), septicaemia, steroid therapy, acute pancreatitis and the fatty liver of alcoholism, though fractures remain the most potent cause of the condition. In burns, there is some doubt whether pulmonary fat embolism is a true ante-mortem process, or whether fat can be melted out of tissues and organs in the perimortal period. Mason's (1968) experience in rapid air-crash fires was that fat embolism was not present, but Sevitt's hospital series revealed embolism in 47 per cent of deaths from burns.

Pulmonary fat embolism

After trauma, fat commonly appears in the lungs and can be demonstrated there histologically in the majority of cases of fractures and injury to fatty parts of the body such as the buttocks. Indeed, Lehman and Moore (1927) showed that half of a series of non-trauma deaths had histological evidence of fat in the lungs. Mason found fat in the lungs of 20 per cent of his series of non-trauma deaths, but emphasized that quantitatively the amount was small in contrast to that found in cases of fatal trauma. He used a simple scale for assessing the histological severity of embolism as seen in Oil Red-O frozen sections of lung:

- Grade 0: no emboli seen
- Grade 1: emboli found after some searching
- Grade 2: emboli easily seen
- Grade 3: emboli present in large numbers
- Grade 4: emboli present in potentially fatal numbers.

In systemic fat embolism, no such grading is possible; they are either absent or scanty, or they are abundant.

In most instances, pulmonary fat embolism is merely a phenomenon and not a clinical syndrome and the difference between the two seems closely related to the amount of fat impacted in the lung vessels. When clinically manifest it appears as acute respiratory insufficiency, the incidence being up to 2 per cent in long bone fractures and as much as 10 per cent in multiple fractures, especially with pelvic injuries. In small to moderate amounts, fat in the lungs gives rise to no disability, but large amounts, easily seen by a cursory glance at any field of a fat-stained histological section, give rise to acute respiratory distress. Marked pulmonary oedema is the pathological marker for this syndrome, but caution must be employed, as cerebral fat embolism can also cause pulmonary oedema by its effect upon the brain.

Systemic fat embolism

Here the fat penetrates the lung capillaries and appears in the major circulation, so that it can be carried to any organ or structure, including the skin, where it can cause petechial-like

Those who have dissected or inspected many bodies have at least learned to doubt, while those who are ignorant of anatomy and do not take the trouble to attend to it, are in no doubt at all.

Giovanni Morgagni 1682–1771
The Father of Morbid Anatomy

Taceant colloquia. Effugiat risus. Hic locus est ubi mors gaudet succurrere vitae.
(Let conversation cease. Let laughter flee. This is the place where death delights to help the living.)

Latin proverb

Seldom say never – seldom say always!

Forensic proverb

Third Edition

KNIGHT'S Forensic Pathology

Pekka Saukko Dr.med.univ. (Vienna), Dr.Med.Sci., Specialist in Forensic Medicine, Dr.h.c.
Professor and Head, Department of Forensic Medicine, University of Turku, Finland

Bernard Knight CBE, MD, DM (Hon), BCh, MRCP, FRCPath, FHKCPath, DSc (Hon), LLD (Hon), PhD (Hon), DMJ (Path), Barrister of Gray's Inn
Emeritus Professor of Forensic Pathology, University of Wales College of Medicine, UK
Formerly Consultant Forensic Pathologist to the Home Office, UK

ARNOLD

A member of the Hodder Headline Group
LONDON