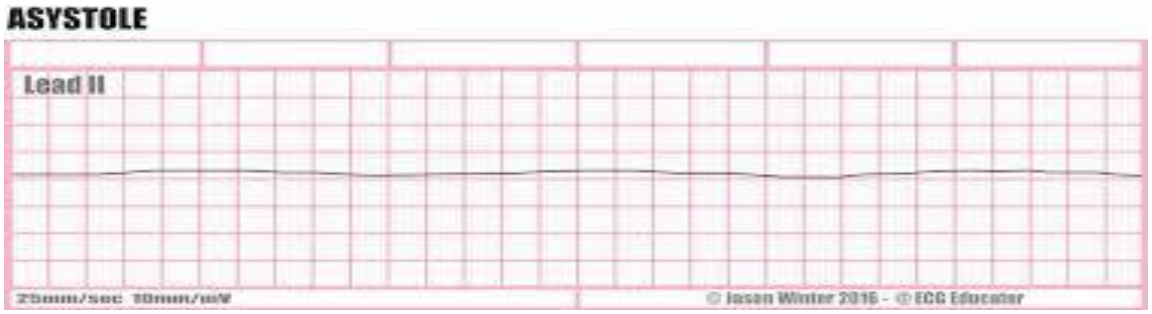
Pathophysiology of death and changes after death:

Core concepts related to death, changes after death and overview of key concepts in forensic medicine:

A) Pathophysiology of death
B) Changes after death

Italics = this is additional information, "nice to know", **not need to know*

A) Pathophysiology of death



a) Death

Life depends on the integrity of three principal interdependent systems - circulation, respiration and innervation. Failure of one of them will eventually cause a failure of the other two and death. The philosophical and theological questions surrounding death are as abundant as the amount of medical literature around the exact "moment of death". This has raised numerous ethical debates, esp around issues of ventilation and persistent vegatative states, which is beyond the scope of this module. Even the legislation is not too clear on defining the exact moment of death and the clarity is left to clinicians to define and elaborate upon. When circulation, respiration, consciousness and brainstem reflexes have ceased this is sometimes referred to as "somatic death". For all intentional purposes somatic death is in fact brainstem death; also known as "brain death". This is because the criteria for diagnosis somatic death are in fact brainstem functions. The death of individual tissues / organs is a process and referred to as "molecular or cellular death". This is why organ transplantation is possible once "brain death" has been declared, but prior to molecular death.

Let's note here that *The National Health Amendment Act* defines "Death" as "Brain Death". This is vital from a legal and ethical perspective and why the diagnosis of brain death is important to know. Let's look at the criteria below:

b) Clinical criteria for death

The following clinical criteria must be satisfied before a Healthcare Professional may declare death:

- Carotid pulses are absent bilaterally
- No signs of breathing are present
- Both pupils are fixed and dilated on examination with a light source
- There is no “doll’s eye” movement on examination of the head
- ECG Reading Asystole

AND

- *Reasonable* resuscitation must have been attempted

AND

- If no resuscitation is attempted the delay between collapse and attention by a healthcare professional is more than thirty minutes

Warning! Exceptions:

- Hypothermia
- Drowning
- Drug overdose
- Poisoning
- Electrocution

An ECG Monitor must be used to confirm death in the above situations

Declaration of death by Health Care Practitioner is unnecessary in cases where persons are obviously dead i.e.:

- Decapitation
- Severe burns with charring
- Severe mutilation e.g. train accident victims
- Post Mortem lividity
- Post Mortem rigidity
- Putrefaction

c) Clinical criteria for brain death

Identifying brain death can be done irrespective of the artificial maintenance of organs such as the heart. The distinction between cerebral death and irreversible coma is of the utmost importance. Cerebral death implies total destruction of the brain with loss of voluntary and reflex functions. Irreversible or very deep coma refers to a state of vegetation in which all functions attributed to the cerebrum are lost, while certain vital functions like respiration and regulation of temperature and blood pressure are retained. (See exceptions mentioned above).

These three criteria must be met prior to diagnosing brain death as per National Health Act:

- The doctor consenting to the harvesting of the organs cannot be part of the transplant team
- Death must be established by at least 2 medical practitioners
- One of these practitioners must have been practising for at least five years after registration

Documentation is key! Crucial for medico-legal and ethical aspects related to consent when it comes to transplantation. These records must include:

"• etiology and irreversibility of coma / unresponsiveness
• absence of motor response to pain
• absence of brainstem reflexes during two separate examinations separated by at least 6 hours
• absence of respiration with $pCO_2 \geq 60$ mm hg
• justification for, and result of, confirmatory tests if used"

(Kumar and Pawar, 2009, The diagnosis of brain death; Indian Journal of Critical Care Medicine; 13 (1) 7 - 11)

THE DIAGNOSIS OF BRAIN DEATH CAN ONLY BE MADE IF THE ANSWER TO ALL THE QUESTIONS IS **NO**

1) Respiration: Is there spontaneous ventilation within 5 minutes of disconnecting the ventilator (with $PaCO_2$ normal before the ventilator was disconnected)?

METHOD: Ventilate the patient with 100% oxygen for 15 minutes. Disconnect the patient from the ventilator. Administer oxygen, 6 l/min, through a catheter in the trachea.

OR

If arterial blood-gas analysis cannot be performed: Ventilate the patient with 100% oxygen for 10 min. Ventilate the patient with 5% carbon dioxide for a further 5 minutes Disconnect the patient from the ventilator. Administer oxygen, 6 l/min, through a catheter in the trachea

2) Brain Stem Reflexes:
    a) Do the pupils react to light? (non reactive)
    b) Do the pupils react to painful stimulation? (must be absent)
    c) Are Doll's eye movements present? (must be absent)
    d) Cold Caloric Test: Does nystagmus occur when each ear is in turn irrigated with ice- cold water for 1 minute?(must be absent)
    e) Is there any movement in the head or neck, either spontaneous or in response to stimulation? (must be absent)
    f) Is there a gag or a reflex response following bronchial stimulation by suction catheter passed down the trachea? (must be absent)
3) Body Temperature: Is the rectal temperature below 35ºC?
4) Drugs: Have any drugs which may affect ventilation or the level of consciousness been administered during the past 12 hours?
5) Cerebral State: Have you any doubt that this patient's cerebral state is due to an irreversible cause?

(See the link attached to the Vula site for Clinical Brain Death Testing, by Dr David Thomson from GSH, UCT: https://www.youtube.com/watch?v=t3COg1qPV9Y)

B) Changes after death

Thanatology is defined as "the scientific study of death and the practices associated with it, including the study of the needs of the terminally ill and their families." We will focus on the pathology aspects thereof, namely the post mortem changes.

A classification of the physical signs can be divided as follows:

a) Immediate
- Cessation of circulation
- Cessation of respiration
- Loss of consciousness
- Absence of all brain stem reflexes
- Primary muscle flaccidity

b) Early
- Algor mortis - cooling of the body (decreased temperature)
- Rigor mortis - stiffening of the body
- Livor mortis - hypostasis / post mortem lividity
- Post mortem dehydration (fluid loss)
- Loss of skin translucency and elasticity
- Secondary muscle flaccidity

c) Late
- Decomposition - autolysis / putrefaction / skletonisation
- Saponification - adipocere formation
- Mummification
- Maceration
- Predation - injuries from animal scavengers

a) Immediate

Discussed above under pathophysiology of death. Some elaboration on primary muscle flaccidity. Immediately after death the muscles relax and lose their normal tone. If the body is placed on a flat surface the body parts in contact with the surface is subjected to pressure and will be flattened, this also called contact flattening and can be associated with corresponding pallor. The face may appear younger as the skin becomes smoothed out.

There are obviously chemical changes in the blood, CSF and other organs as well which will not be focused on here.

b) Early changes after death

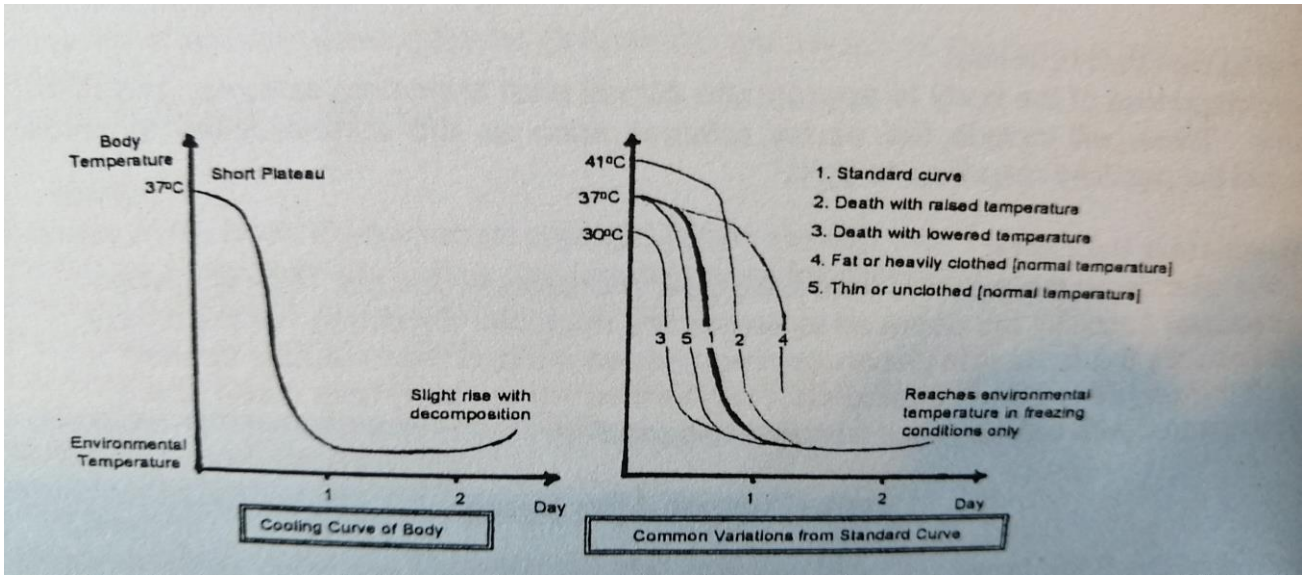
1) Algor mortis - cooling of the body (decreased temperature)

Heat is lost to the environment due to convection, conduction and radiation. This happens despite the fact that the insulating properties of skin and subcutaneous tissue are about equal to those of cork, since heat loss is not compensated for, as happens during life, by the body's own metabolic processes.

Unless the surrounding environment's temperature is more than the body temperature cooling will occur. The temperature drop is slow at first due to a continuation of some cellular activity (the temperature may even rise a little), but thereafter the drop is fast, to slow down again as environmental temperature is approached. This forms a so-called sigmoid shaped curve.

<u>The S-shaped time/temperature cooling curve consists of:</u>

- An initial plateau 1-3 hours (due to heat still produced by post-mortem anaerobic glycogenolysis)
- A falling straight line, 3-12 hours (more rapidly on skin)
- A slow-falling exponential curve



** Formulae used to determine the time of death are unreliable because they do not take the first phase of cooling into account, nevertheless, the most accurate formulae are those that take the environmental temperature into account. In general, the drop in temperature multiplied by a factor (determined by the environmental temperature) gives the approximate post-mortem interval.*

Environmental Temperature in ºC	*0*	*5*	*10*	*15*	*20*
Factor	*2*	*1.75*	*1.5*	*1.25*	*1*

e.g.: Body temperature is 31ºC. Environmental temperature is 10ºC. Temperature drop in body is 6 (from normal body temperature of 37ºC). Using the appropriate factor: 6 x 1,5 = 9 hours (after death). This is an estimation only. This table has limited use in SA with high ambient temperatures, esp. in summer. Ignorance of body temperature at the start of cooling will limit the accuracy of death timing. Standard "cooling curves" make allowance for varying operative parameters. However, no formula produces consistently good results.

Under average conditions the environmental temperature will be reached within 28 hours for the average, 41 hours for the obese, and 19 hours for the very thin cadaver.

The rate of cooling is influenced by:

- Body factors:
  - Initial body temperature: presence of infection (septicaemia / bacterial activity), physical exertion, severe haemorrhage, poisonings (carbon monoxide)
  - Body build: skinny vs obese, adult vs. child
  - Posture of body (surface area exposed to cooling): crouching/ foetal or supine
  - Body covered in clothing or naked
- Environmental factors:
  - Ambient temperature: eg. outside exposed in summer vs inside a house
  - Body in water: cools more rapidly in water
  - Movement of air: wind outside or open window in house near body
  - Humidity of air: heat better contained in damp air
- Site of measurement:
  - Skin (least accurate)
  - Rectum
  - Sub-hepatic (more accurate to core temp.)

Medico-Legal Importance of Body Temperature:

- If height, mass, intrinsic and environmental factors are known and the cooling rate pattern has been established by three serial temperature readings taken at 1 hour intervals, the approximate time of death *can be suggested*.
- It may be of value to distinguish between primary and secondary muscle flaccidity.
- It influences the onset and development of putrefaction and rigor mortis

2) Rigor mortis - stiffening of the body

This is the state of generalised muscle rigidity which follows primary flaccidity in all voluntary and involuntary muscles.

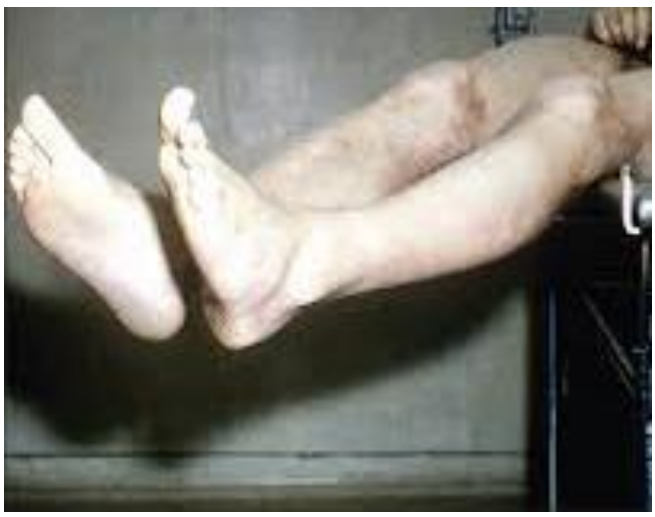
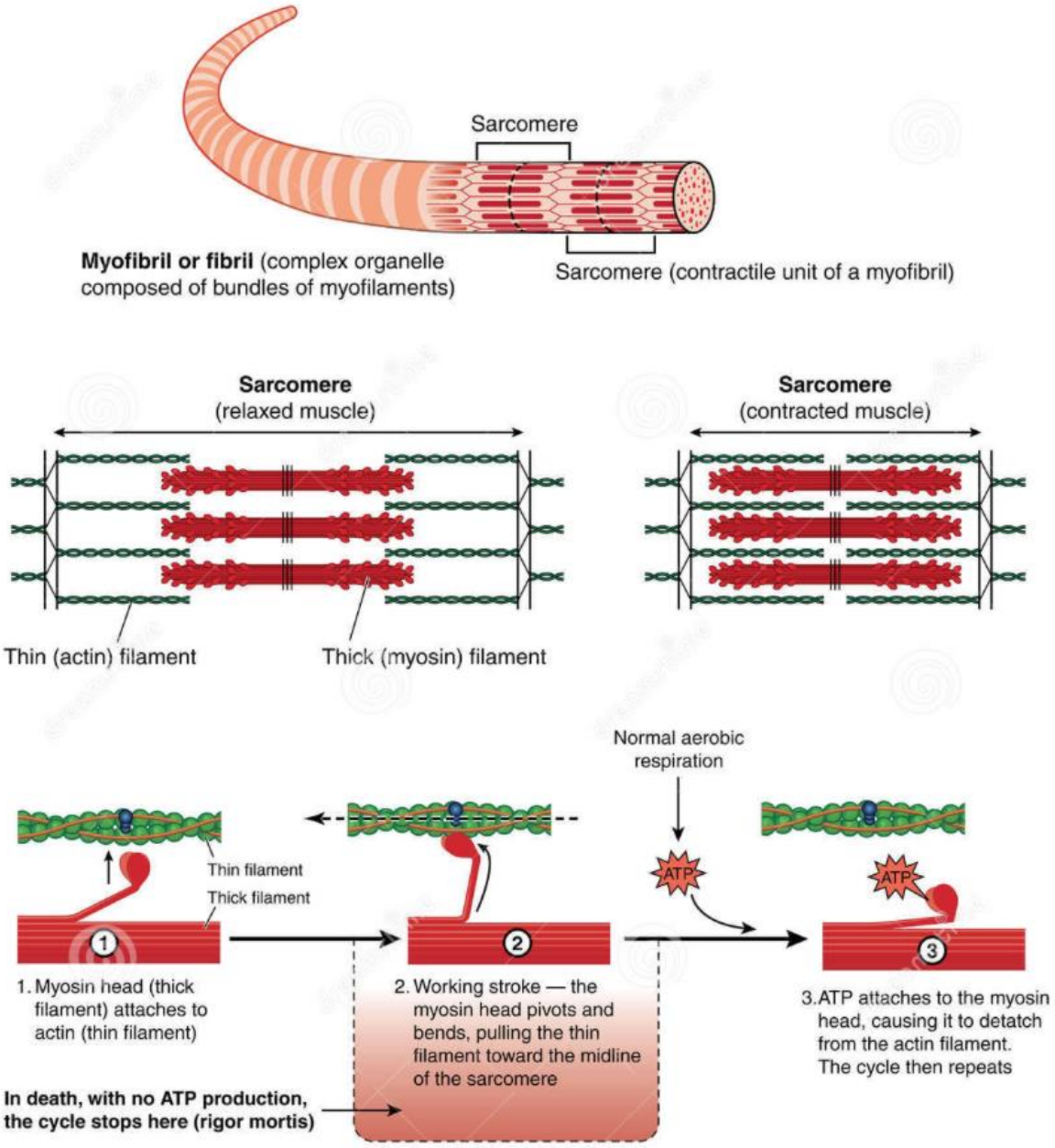


Fig. 1_Rigor mortis

The normal plasticity of a muscle before and after death is dependent upon muscle ATP levels. Anaerobic glycogen metabolism after death continues to liberate energy for ATP resynthesis. When this ceases ATP resynthesis is not maintained. The reduced ATP levels which follow are accompanied by chemical bonding between actin and myosin to form acto-myosin which causes the muscles to become hard, stiff, and only very slightly shortened.



**Gastrocnemius muscles in rigor mortis were observed by electron microscopy. The prominent appearance of many fine cross striations in the myofibrils (occurring about every 400ºA) was due to granules studded along the surfaces of both thick and thin filaments and appeared to be the bridges connecting the two kinds of filaments and which may account for the hardness and rigidity of the muscle.*

Rigor mortis (under average conditions) is noticeable in smaller muscle groups within 2-4 hours, obvious by 6-8 hours, fully established by 12 hours and generally passes off after 24 hours, with resulting secondary flaccidity by 36 hours.

Rigor mortis develops simultaneously in all muscle groups, but manifests itself first in the smaller muscle groups, then the larger groups, and passes off in the same order as it sets in. Once artificially broken down it will not set in again. Asymmetrical appearance of rigor mortis in the body with some limbs rigid and others flaccid, suggests that interference of the body (with breaking of rigor mortis in some limbs) after establishment of rigor mortis, has taken place. Paradoxical appearance of rigor mortis, e.g. body found on back with rigid limbs extended above the body suggests alteration of body position after full rigor mortis had already set in. Eventual denaturation of muscle protein results in **secondary flaccidity**.

<u>The time of onset of rigor mortis may vary considerably as influenced by:</u>

- Residual muscle ATP at time of death:
  Debility or intense muscular activity prior to death reduce ATP levels, with more rapid onset of rigor mortis.
- Rate of ATP breakdown:
  - optimal temperature accelerates enzyme mediated ATP breakdown
  - cold temperature delays ATP breakdown and thus onset of rigor mortis

<u>Rigor mortis is to be differentiated from:</u>

- Cadaveric spasm (instantaneous rigor):
  This may affect a limb, limbs or the whole body and occurs occasionally at the moment of death in cases of emotion-charged sudden death. (Modification of true rigor mortis?) The spasm passes into rigor mortis and passes off with rigor mortis. The hand in cadaveric spasm may grasp a suicide weapon, reeds from the river bank, or buttons or fibres from the assailant's clothes. If the causal weapon is found grasped in the hand in cadaveric spasm it may suggest suicide, but may be artefactual, to cover-up a homicide.
- Cold stiffening and freezing of joints:
  Crepitation of breaking ice crystals can be felt when joints are moved (occurs at temperatures below 4ºC). Rigor mortis is delayed and sets in only on thawing, if the body was frozen prior to rigor.
- Heat Rigor:
  This is the result of heat coagulation of muscle protein with marked shortening (NB) of the muscle group. This may even give rise to tears of skin and subcutaneous tissue, to be differentiated from ante-mortem wounds. Due to flexioncontraction the body may adopt a pugilistic attitude (body in boxer position) because of the greater mass of flexor muscles. Heat Rigor is no indication of whether the person was alive or dead when the body was burnt.
- Ankylosis of joints: fixation of joints during life
- "Fat Rigidity":
  Cooling of subcutaneous fat after death. Seen most frequently in infants.

Medico-legal importance of rigor mortis:

- May be of value in estimation of approximate death interval.
- Paradoxical distribution may suggest interference with the body after onset of rigor mortis as the position of the limbs in rigor-mortis may be incompatible with the position in which the body is found.
- Partially broken rigor mortis may indicate interference with the body after the development of rigor mortis. (i.e. hours after death)

3) Livor mortis - hypostasis / post mortem lividity

When the circulation of blood stops the stagnant blood moves to the lowest part of the body because of gravity. The discoloration of the body secondary to the gravitation of blood into the dependent capillovenous bed in the skin, subcutaneous tissue and organs is called livor mortis / hypostatis or post mortem lividity (Fig. 2). Lividity may not appear in areas where pressure has occluded vessels (see a) Immediate post mortem changes above).

Time of appearance is variable but, depending upon skin colour and volume of blood in the vascular system, it usually manifests itself within 30 minutes to 2 hours and is partially fixed due to coagulation and haemolysis within 4 hours. It is usually fully fixed at 8 to 12 hours.

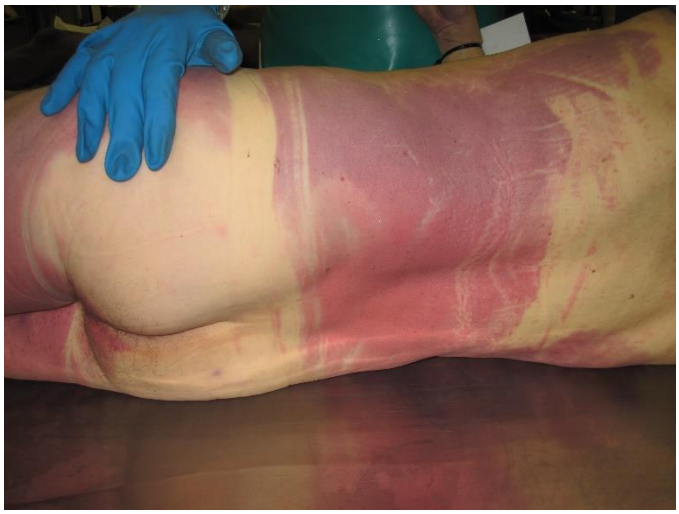


Fig. 2_Hypostasis

Factors influencing appearance and visibility:

- Skin colour of deceased
- Amount of blood in body:
    - Haemorrhage
    - Anaemia
- Viscosity of blood
- Time since demise
- Fixed posture since demise
- Pressure points
    - Clothing (belts etc)
    - Position body on certain surface

Must be differentiated from the following:

- Bruising:
  WIth bruising the blood is extravascular. By cutting through the skin into subcutaneous tissue, it will be clear that in areas of lividity the blood is still in the vessels and not in the interstitial tissue, as with a true bruise.
  This includes distinguishing bruising from hypostasis in gravity dependant organs.
- Inflammation:
  - Cellulitis etc

Medico-legal importance:

- Paradoxically distributed lividity suggests that the body was moved after partial or complete fixation of lividity.
- Colour of lividity may suggest poisoning:
  - bright red/pink: Carbon Monoxide , cyanide, effect of refrigeration
  - Green / blue / black: decomposition
  - chocolate-blue-brown: methaemoglobinaemia with potassium chloride and nitrate poisoning
  - Spotty bronze: *clostridium perfringens* septicaemia
- Help in estimation of approximate death interval
- Pressure effects from clothing e.g. tight collar causing pallor marks in areas of lividity, must not be confused with strangulation marks
- Note distribution e.g. in hanging, lividity will be in dependent parts if it was fixed prior to cutting down of body
- Putrefaction sets in earlier in livid tissue

4) Post mortem dehydration (fluid loss)

Natural fluid loss occurs post mortem. The skin becomes dry, eyeballs loose their pressure (Fig.3) and the lips dry out. If the eyelids are open at the time of death the underlying exposed (to air) conjunctiva can become brown, and even blackish and is called *tache noir (Fig.4)*. An extreme form of fluid loss occurs in specific ambient conditions and is called mummification. See later.

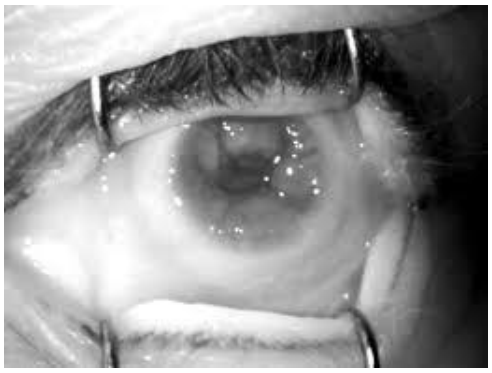


Fig. 3_loss of fluid in eyeball post-mortem

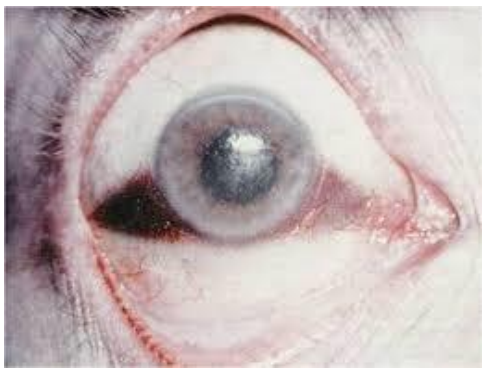


Fig. 4_*tache noir*

5) Loss of skin translucency and elasticity

6) Secondary muscle flaccidity

Once the initial rigor mortis passes off the muscles starts breaking down and decomposing.

C) Late changes after death

1) Decomposition - autolysis / putrefaction / skletonisation

Putrefaction (process of decay) and autolysis (destruction of a cell through the action of its own enzymes) take place concurrently. This gradually result in all the tissues dissolving into gases, liquids and salts. This is caused by proteolytic and other enzymes produced by bacteria. This activity is due to the invasion of the blood and tissues by normal body flora and/or pathogenic organisms associated with death, e.g. Cl. welchii micrococci and proteus organisms. In septic abortions there may be greatly accelerated putrefaction, despite refrigeration.

<u>Putrefactive changes can be categorised broadly as:</u>

- Changes in colour:
    - Initially in localised areas, e.g. lower abdominal quadrants as a blue-green discoloration, or later green-black.
    - Or in blood vessels as red staining in walls.
    - Haemolysis in vessels can cause a marbling effect in skin (Fig. 5).
    - Putrefactive desquamation of the skin reveals a moist pink under-layer.

- Gas formation:
    - Various gases are formed during putrefaction including; hydrogen, methane, ammonia and carbon dioxide. These are responsible for the offensive odour.
    - These gases distend the tissue, giving a bloated appearance, esp. notable initially as a distended abdomen (Fig.5).
    - Rising gas pressures can cause the stomach contents to come out and feces from the rectum.
    - Blood-stained froth may also be noted associated with gas formation.
    - Later the gas formation on the subcutaneous tissues causes the face and neck to appear bloated and the eyes to appear proptotic.
    - External genitalia can be markedly distended (testis)
    - May form skin blisters and even bubbles in the organs.

- Liquification Internal organs:
    - Over time the tissues of the body undergo softening and liquefaction.
    - The rate of liquefaction differs from tissue to tissue
        - The brain often liquifies fast
        - The capsules of the liver, spleen and kidneys resist putrefaction longer, causing a bag-like effect filled with thick material.

        - Organs most resistant are the heart, lungs and uterus. These may remain recognizable as such for months after death, and may help in determining the gender of the deceased in late stages of decomposing.

Factors influencing putrefaction progression:

- Extrinsic factors:
    - environmental temperature: lower temperatures inhibit bacterial growth (hence bodies being refrigerated asap after death)
    - Water: putrefaction slower than on land, (see below rate of putrefaction for more details)
    - Moisture:
        - warm and humid air with air movement accelerates putrefaction.
        - warm and dry air with little movement are favourable for mummification to occur (see below).
- Intrinsic factors:
    - age: putrefaction usually more rapidly in children
    - body build: obese individuals decompose more rapidly
    - nature of death,
    - distribution of lividity,
    - state of tissue hydration: example in death following severe vomiting and diarrhoea
    - extent and nature of injuries: may be accelerated in deaths due to acute infections - septicaemia
    - Autolysis may take place under sterile conditions - e.g. macerated foetus.

Rate of putrefaction:

- Putrefaction may manifest itself within hours of death: at 30ºC putrefaction may become obvious within 24 hours.
- When the body becomes putrid, hair and nails are pulled out easily and the skin may slip off over large areas.
- Fingerprints may even be taken if the skin of the hand is slipped off entirely and pulled over the dissector's gloved hand, like a glove.
- If a body is left in the open, larvae are usually present, especially in body orifices.
- In water:
    - Due to gases of putrefaction the body may rise to the surface, even if immersed with weights:
        - in fresh water within 7 days
        - in sewage-contaminated water within 2 to 3 days
        - in deep sea-water it may remain submerged for weeks
    - The body is often reduced to skeletal remains within 10 years.

Medico-legal importance decomposition:

- An opinion as to the post-mortem interval must be guarded.
- Avoid confusing areas of putrefactive discoloration from bruising or putrefactive changes from pathological states:
    - gas bubbles in vessels from air embolism
    - putrefactive gas blisters may resemble scalds

    - gas distension may cause the tongue to extrude as in strangulation, force the foetus from the uterus, blood and fluid from orifices and food from stomach into respiratory tract
- Putrefactive gas disruption of tissue must not be mistaken for ante-mortem wounds
- Charring of the body by destroying bacteria should prevent putrefaction. Putrefaction of a charred body may therefore indicate that the body was burnt after death after early putrefaction had already taken place.
- Enzyme inhibition (sodium fluoride poisoning) should prevent autolysis.

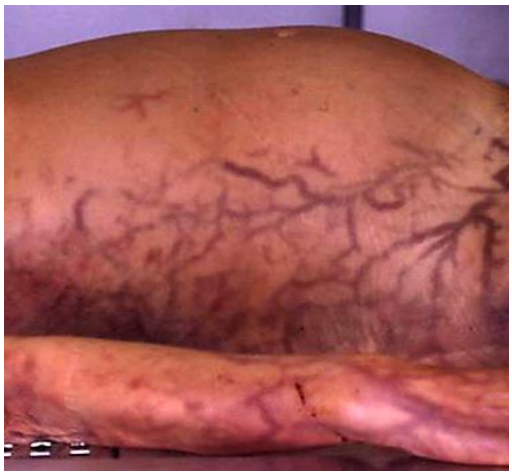


Fig. 5_ marbling and bloated abdomen

Fig. 6_ adipocere

2) Saponification - adipocere formation

This generalised or localised change results from post-mortem hydrolysis and hydrogenation of body fat, with resultant preservation of subcutaneous tissue by waxy material which is soluble in alcohol and melts on heating, with a waxy appearance (see Fig. 6 above) when cold and an oily appearance/texture when warm. The smell ranges from odourless to rancid.

The formation of adipocere is due to Cl. welchii lecithinase activity on body fat with formation of fatty acids which in turn inhibits further putrefactive bacterial activity. Its formation is usually associated with cold and moist conditions and it is therefore frequently found in bodies in wet graves. It may occur within weeks of death, but usually takes months.

<u>Medico-legal importance of saponification:</u>

- Good preservation of body and facial features facilitates identification long after death and preserves wounds.
- Rough estimate of death interval

3) Mummification

This occurs, as mentioned above already, if the body dries out after death in hot, arid conditions, which, if sufficiently rapid, halts decomposition, and the tissue becomes hardened and darkened.

The rapidity of the process depends on a variety of intrinsic and extrinsic factors such as air movement, degree of (or absence of) humidity, heat, body build, tissue hydration, character of burial site, e.g. dry arid conditions of deserts. Mummification may follow certain diseases and poisonings due to severe dehydration. It may occur in weeks, but development is generally very variable and persists for years as in Egyptian mummies.

Medico-legal importance of mummification:

- preservation of the body facilitates identification long after death and
- preserves wounds, can aid in determination of the cause of death
- Not of value to estimate death interval

Fig.7_mummification (form of severe dehydration of tissues)

4) Maceration

Form of decomposition occurring when a foetus dies in-utero and remains in the amniotic sac. Externally large moist blisters may be seen on the skin. As these blisters rupture they may appear red-brownish over the skin surface. The internal organs become soft and discoloured. AS the process involves soft tissues the limbs and gradually the bones are loosened from their attachments. These signs take time to develop and are consistent with death for several days prior to delivery. This may be significant in concealment of birth cases where a foetus was found in an unknown place, obviously signifying death prior to delivery.

5) Predation: injuries from animal scavengers.

Post-mortem tissue destruction by animals, birds, fish, crustaceans, ants, larvae may be mistaken for ante-mortem injuries. Ant erosions may appear shortly after death and appear as dry and parchment-like superficial abrasions. Maggots in tissue may suggest minimum death time. By performing a complete entomological investigation valuable information regarding the post mortem interval may be established.

**The following specimens can be retained in an entomological investigation:*

- *soil or material underneath the body*
- *live maggots from the body*
- *maggots from the body preserved in 70% alcohol to arrest further development*