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Lethal Traumatic Injuries due to Traffic Accidents

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Although in recent years there has been progress towards improving road safety legislation and in making vehicles safer, the report highlights that the action to combat this global challenge has been insufficient [1].

Lethal injuries occur in all forms of transportation but statistically road traffic accidents account for the vast majority in the world.

Most common cause of death in car accidents is head injuries followed by chest and abdomino-pelvic injuries [2]. A. Ndiaye report that the most frequently injuries responsible for death affected the thorax (62% of casualties), the head (49%), the abdomen (10%), and the spine (9%) [3].

There is some evidence on effectiveness of digital autopsy in determining the cause of death due to blunt trauma following traffic accidents [4].

Postmortem cross-sectional imaging, including computed tomography (CT) and magnetic resonance imaging (MR), has been an established adjunct to forensic pathology for approximately a decade [5].

Although imaging in postmortem investigation is performed since radiography (X-rays) itself exists, recently the use of heavy imaging techniques has been improved to assist or supplant conventional autopsy in postmortem investigation [5].

PMCT technique is increasingly implemented into forensic medicine thanks to the possibility to re-assess data through the use of multiplanar and volume rendering reconstructions.

While there are few who doubt the ability of PMCT to detect fractures, foreign bodies, and major hemorrhagic injuries, there have been many false dawns in this field.

On the other hand, a growing filed is represented by postmortem MRI (PMMR) which has a high sensitivity and specificity especially in the evaluation of soft tissue, nervous and cardiovascular systems. A major limiting factor of PMMR is the high cost of the technique, which is not widely available. Furthermore another limitation is the long examination time for a whole-body study, which is required to completely evaluate the deceased.

For this specific reason, PMMR evaluation, when requested and possible to apply, must be focused on specific anatomic region of interest.

An important tool of PMMR is the evaluation of certain areas, such as the subcutaneous fat of the extremities, the spine and the back of the torso improving examination before autopsy.

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However, it has been reported in literature that whole-body MRI for postmortem imaging compared with classic autopsy in cases of a traumatic cause of death showed overall good performance of this technique in the visualization of major life-threatening pathologic conditions [6].

It is important to underline also that some findings, easily recognized at PMCT and PMMR, can be missed during autopsy if not depicted before the beginning of the conventional procedure such as pneumothorax, pneumomediastinum, and gas bubble in the vessels.

10.1 Head Injuries

Head injuries commonly occur as consequence of direct impact to the head; rapid acceleration/deceleration of the head with or without a head impact. The probability of lethal injuries depends on the impact velocity and on the size and type of vehicle involved in a crash.

The most common head lethal injuries include:

- Skull fractures.
- Vertebral dislocations and fractures.
- Epidural, subdural, subarachnoid hemorrhages.
- Brain and spinal cord contusions, lacerations and hemorrhages.
- Intraventricular hemorrhage.
- Diffuse brain injury (swelling, axonal injury, hypoxic-ischemic injury, vascular injury).

The fracture skull bones are distinguished into linear fracture, depressed fracture, comminuted fracture, and ring fracture. The various pattern of injuries are caused by direct contact from objects and/or energy transfer to sites remote from the impact site.

Basilar skull fractures are defined as linear fractures in the skull base, and are often associated with facial fractures that extend to the skull base. The sphenoid sinus, foramen magnum, temporal bone, and sphenoid wings are the most common areas of these fractures.

The most common site of skull base fracture is the anterior vault followed by the middle and the posterior region. Basilar fractures tend to run along the length of the petrous ridges passing through the sella turcica (“hinge fractures”). Less common are ring fractures and multiple fracture lines of the base of the skull.

The clivus is the strongest bone of the skull base and provides mechanical support for the cranial vault and protection for the brainstem and adjacent major vascular structures. Despite its deep location it is very susceptible to related fractures and a high mortality or at least a poor outcome for survivors related to concomitant injuries of the brainstem, lower cranial nerves, and vertebro-basilar artery.

In general, clivus fractures are hardly detected on conventional radiography, contrariwise to cross-sectional imaging such as CT, and is usually a detectable autoptical finding (Figs. 10.1 and 10.2).

As reported by Corradino et al. [7] the clival fractures are classified according their CT

Fig. 10.1 A hinge fracture of the base of the skull. The fracture line runs from side to side across the floor of the middle cranial fossa, passing through the pituitary fossa in the midline. The victim was a young who died following front impact crash while sitting in the front passenger seat

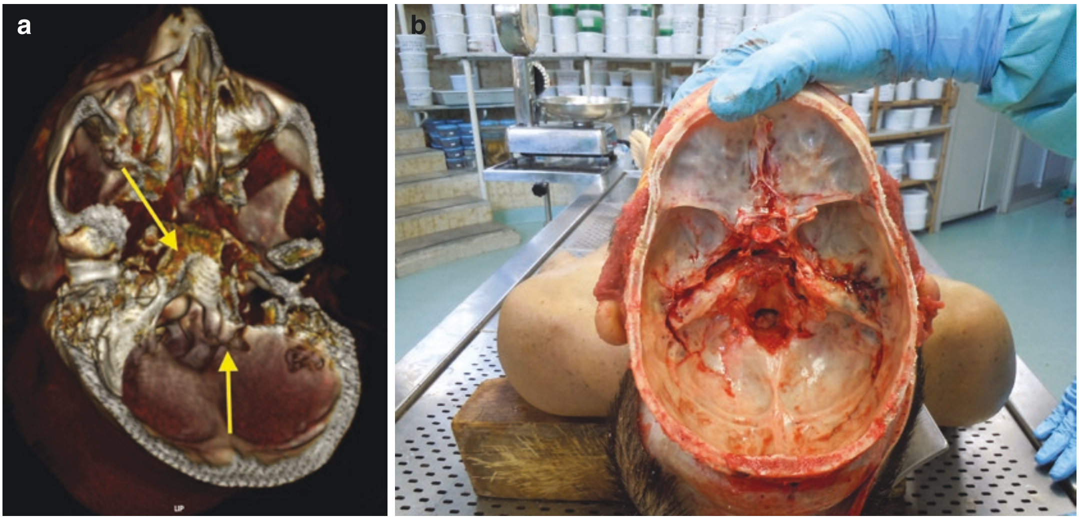

Fig. 10.2 (**a**) Para-axial volume rendering reconstruction image shows two fractures of the base of the skull with their direction and length (yellow arrows). The victim was a young man who died after a smash-up while he was stopping on his motorcycle. (**b**) The same traumatic fracture of the skull base at autopsy

imaging as longitudinal, transverse, and oblique. Longitudinal types are usually caused by frontal or axial impact and are associated with the highest mortality (67–80%), related to the concomitant injuries of the brainstem, lower cranial nerves, and vertebro-basilar artery. As reported in forensic literature, the oblique or transverse clival fractures usually occur after a severe axial blow and have been often implicated in damage of the carotid arteries [8].

Traumatic intracranial hemorrhages occur in the following sites:

- Epidural space
- Subdural space
- Subarachnoid space.
- Intracerebral hemorrhages

The **epidural hemorrhage** is generally due to avulsion and rupture of the diploic veins or stretching and tearing of a sinus wall. It may be the result of transection of the middle meningeal artery by a skull fracture that passes through the middle meningeal groove. Extradural hematomas is usually in the temporal or parietal regions, where an impact to the temporal bone causes a fracture of the squamous temporal bone. These hemorrhages may occur over any portion of the hemispheres or in the posterior fossa and are much slower.

The **acute subdural hematomas** is caused by a tear of the bridging veins between the cortical surface and the dural sinuses or small artery on the cortical surface. Acute subdural hematomas is usually associated with head trauma severe enough to cause skull fracture and cerebral contusion or laceration. Acute subdural hematoma (ASDH) is generally associated to diffuse axonal injury (DAI) produced acceleration/deceleration forces. The mortality is extremely high and the residual dysfunction of survivors is severe.

The **subarachnoid hemorrhage** may be focal or diffuse as sequel of head blunt trauma or it is secondary to a rupture of vertebral artery or dissection of vertebra-basilar artery due to blunt cervical trauma particularly by rapid deceleration of the high-speed motor vehicle crashes.

Rarely a closed head injury is complicated by a rupture of vertebral artery or vertebral artery aneurysm [9].

Generally, a vascular injury after a blunt cervical trauma results either from shearing forces secondary to rotational injuries or from direct trauma to the vessel wall from bony prominences. Distraction/extension, distraction/flexion, and lateral flexion injuries have been implicated as

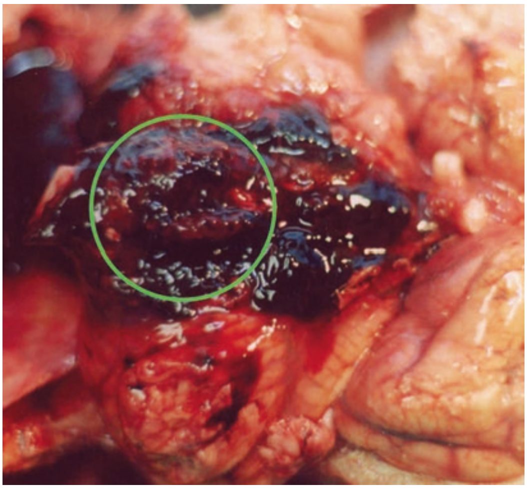

Fig. 10.3 A rupture of fusiform aneurysm of right vertebral artery observed in a 13-year-old female due to blunt cervical trauma following a traffic accident

major mechanisms of injury in vertebral artery. Moreover, either distraction/extension or distraction/flexion injuries could easily be elicited by the rapid deceleration of the high-speed motor vehicle crash (Fig. 10.3).

Intracerebral hemorrhages are, also, common in severe head injuries. Some are primary, occurring at the time of impact or soon afterwards; others are secondary and caused by changes in intracranial pressure or bleeding into infarcts caused by vascular damage.

At PMCT intracranial hemorrhages are not different if compared with alive and are well detectable as intraparenchymal, epidural, subdural, or subarachnoid hemorrhage [10] (Figs. 10.4 and 10.5).

Fractures of the calvarium, the skull base, and the facial bones can be rapidly detected at PMCT before tissue dissection [11].

Despite PMCT has a low performance value in detecting soft tissue injuries and parenchymal injuries, PMCT findings such as traumatic decerebration, external brain herniation, crush fracture of skulls, massive intraventricular hemorrhage, and cerebral venous gas emboli due to secondary open skull-fractures are sufficient to underline the cause of death [11–13].

Another important tool of traumatic lesions detected at PMCT is intraocular hemorrhage: in the most of cases it is due to orbital and skull base fractures which sometimes can be not evidentiated by performing conventional autopsy [14].

The role of PMCT in cases of cerebral venous gas emboli is important because it could be

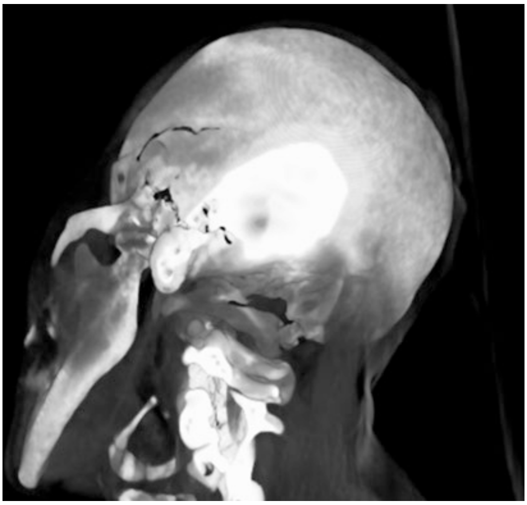

Fig. 10.4 MIP 3D volume rendering reconstruction shows a wide fractures of the plank head from the medial third of the occipital bone suture to parietal bone and subluxations of the atlo-occipital articulation

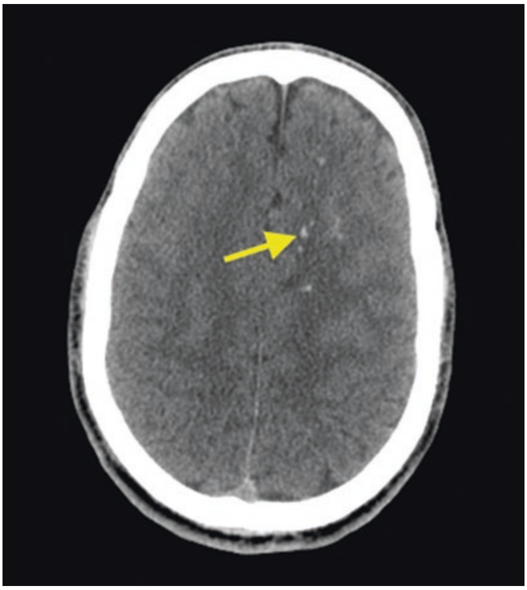

Fig. 10.5 Unenhanced CT of the head after motorcycle accident highlights the presence of subarachnoid hemorrhage and microhemorrhages in the corona radiata

missed during conventional autopsy although modified autopsy techniques to detect air are employed.

Moreover signs which make high suspicion of cerebral venous gas emboli include gas in the cerebral venous sinuses, right heart, supracardiac neck veins, and pulmonary artery [11].

Embolism has to be suspected when there are the absence of subcutaneous emphysema, absence of air in the left side of the heart, and air only in the hepatic veins without portal venous gas [15]. Specificity, sensitivity, and accuracy in the detection of subarachnoid hematoma, subdural hematoma, and epidural hematoma are really high at PMMR, as reported by Ross et al. [6]. In the same study, in cases of intraparenchymal hemorrhage of brain tissue, PMMR had a sensitivity of 80%, with good concordance with that of autopsy [6].

Moreover PMMR is sufficient for the evaluation of findings identified as coup or contrecoup lesions by the autopsy [16].

As reported in literature, the coup lesion occurs in the same site of the primarily impacted area, with the contrecoup lesion occurring on the opposite site. About this, when possible, it is important both for the pathologist and the radiologist to know how was the trauma to calculate the impact vector, important for the forensic reconstruction of the head trauma [16].

During PMCT of the head after trauma it is important to be aware about some unspecific postmortem signs which may not be related to the trauma itself. In particular, loss of cortico-medullary differentiation, brain swelling, hyperdensity of sagittal sinus and cerebral veins, and the presence of gas bubbles are not necessarily related to the trauma.

The loss of cortico-medullary differentiations is due to postmortem hypoxia which leads to edema reducing the border between the cortex and medulla of the brain. However, to increase the specificity of postmortem imaging investigation, we have to underline that performing PMMR, the cortico-medullary differentiation remains after weeks and can help to identify brain structure in other type of traumatic death.

Brain swelling is also related to hypoxic edema formation and results in the increasing size of the brain with reduction of the volume of the sulci, cisterns, and ventricles, often associated with intracranial hernias [17].

Thanks to the sedimentation effect of the static flow of the blood after death, hyperdensity of the vessels is a common finding. Blood clots are always located on the backside of the body, if the deceased lies on the back, and at imaging revealed a brighter imaging of the posterior sagittal sinus compared with other sinus. Also cerebral veins may appear brighter but it has to be not confused with subarachnoid hemorrhage.

Moreover the presence of gas bubbles has to be correlated to bacterial putrefaction that begins after a short time after death. The same pattern is seen in the whole body. The most important feature to underline in this case is the diffuse distribution of putrefaction gasses, which is not common in cases of embolism or trauma [18].

Postmortem fractures of the body can occur due to accidentally sloppy during transfer to and from the CT couch. Communication with the forensic pathologist regarding the initial external inspection or later inspection during autopsy is relevant to avoid mistaking postmortem fractures for antemortem findings. On the other hand, indirect signs of antemortem fractures, such as hematoma on PMCT or bone bruises on PMMR, might be present. Nevertheless, bone marrow edema can also occur as a result of heat-related bone changes due to thermal impact with potential pitfalls findings [19].

10.2 PMMR vs. PMCT vs. Autopsy

Radiological techniques and conventional autopsy are equivalent for the diagnosis of skull fractures. Facial bone fractures are better identified at PMCT than autopsy. In the evaluation of brain tissue injuries, PMMR is found to be sufficient for the evaluation of typical blunt head trauma injuries [6, 20].

Hemorrhages are well identified with a good diagnostic agreement both by autopsy and radiological techniques, although subdural hematomas and subarachnoid hemorrhages are visualized slightly better with autopsy than PMCT and

PMMR. However intraventricular hemorrhages are well detected at PMCT, due to the complexity of findings of the injured brain tissue after meninges are opened at autopsy [11].

Smaller hemorrhages are often missed with both PMCT and PMMR, although the role of these injuries is important in forensic medicine.

Extra-axial hemorrhages are better investigated with higher specificity through PMMR than PMCT [20, 21].

10.2.1 Brainstem Injuries

Traumatic lesions of brainstem most commonly occur on pontomedullary junction. The most common mechanisms of pontomedullary lacerations include impact to the chin, with or without a skull base fracture, lateral and posterior head impacts with subsequent hinge fractures, fronto-posterior hyperextension of the head [22].

In all the cases with pontomedullary laceration posterior neck dissection should be performed during the autopsy, since upper spine injuries are often associated with this type of injury (Fig. 10.6).

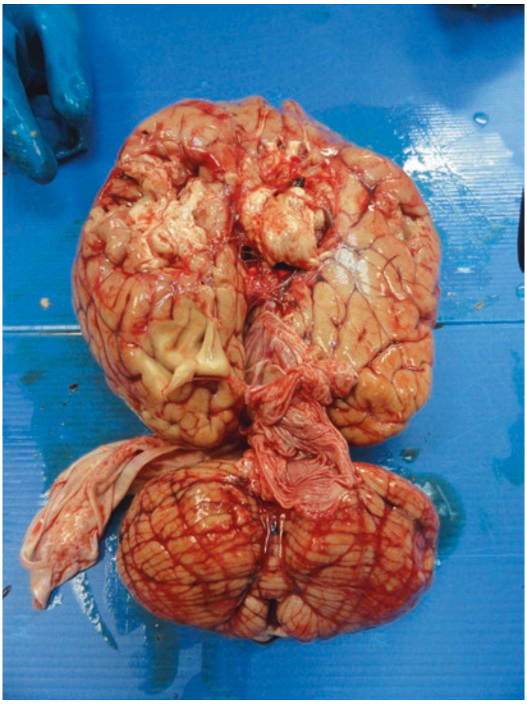

Fig. 10.6 Longitudinal brainstem laceration associated with complex basilar skull fractures observed in a young woman due to blunt head trauma following a traffic accident

10.2.2 Spine Injuries

The cervical spine is susceptible to injuries during hyperextension or hyperflexion of the neck. The introduction of PMCT has significantly improved diagnostic accuracy of cervical spine examination [23] (Fig. 10.7).

One injury that is frequently overlooked at autopsy is the atlanto-occipital dislocation not easily detected at conventional autopsy. Other fractures can occur anywhere in the cervical spine, often at about C5–C6 level. Seatbelt restraint cannot prevent cervical spine damage, though a rigid head restraint can reduce injuries resulting from hyperextension. The thoracic spine is less often damaged, but in unrestrained drivers the same “whiplash” effect can fracture or dislocate the upper dorsal spine, often around T5–6–7 level.

PMCT has a strong limit in the detection of cervical cord injury and discoligamentous injury which can be seen only on PMMR, although it can be suspected if spine fractures are present [12].

Spinal cord injuries without radiographic abnormalities (SCIWORA) are well-known entity, first described in 1982 by Pang and Wilberg. This entity includes normal findings on radiographs, but detectable on MRI studies only if spinal cord has been visualized.

However, most traumatic changes can be easily detected and characterized at PMCT, although SCIWORA are a potential pitfall in PMCT. Spinal cord injuries (SCIs) characterized by bone fractures at PMCT can be easily detected at PMCT.

Ossification of the posterior longitudinal ligament, spinal stenosis due to cervical spondylosis, ossification of the ligamentum flavum, diffuse idiopathic skeletal hyperostosis, fused vertebral bodies, and ankylosing spondylitis are often detected at PMCT and can be considered

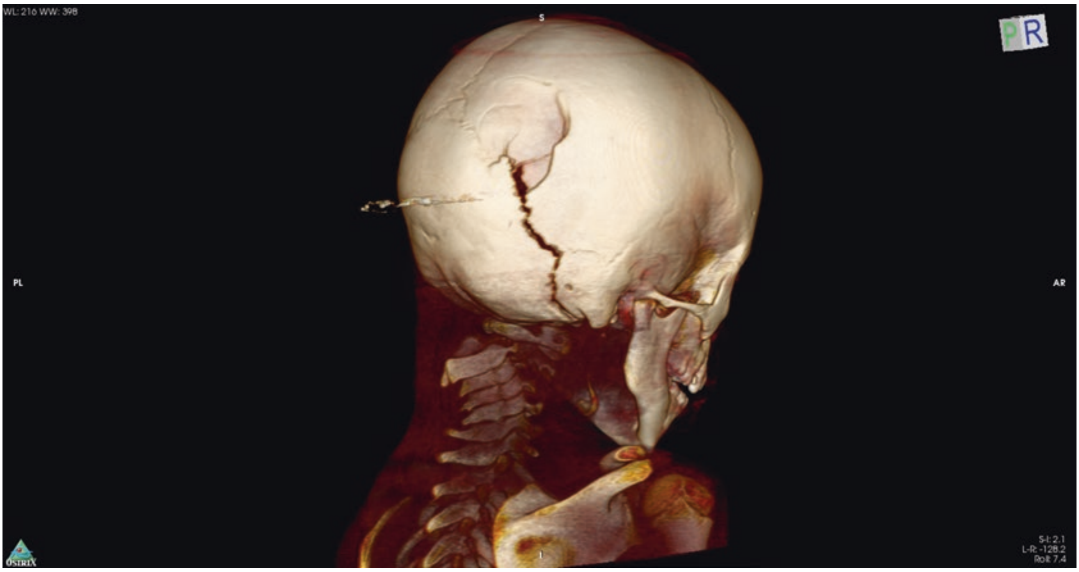

Fig. 10.7 Atlanto-axial joint dislocation associated with fracture of odontoid process at CT scan image observed in a young woman due to airbag

to be associated with SCIs and also with SCIWORAs [24, 25].

Spinal cord injuries can be seen at PMCT and are identified also by the presence of hemorrhages and contusion in the spinal cord also without transection or severe deformity, some only detectable microscopically.

Fractures, on one hand, are well recognizable at PMCT. On the other hand, it is not easy to detect intervertebral disk injuries, although PMCT is useful in identifying dislocations, tears, and hemorrhage, but sometimes are very difficult to identify without subluxations. Perivertebral hemorrhage is always associated with SCIs and easily recognized at PMCT.

As reported by Makino et al., SCIs with apparent transection or severe deformity, which can lead to immediate death, are sometimes detectable at PMCT. However contusions and tiny hemorrhages were more frequent at autopsy, but could not be identified at PMCT because of artifacts from teeth and bones. On the other side, SCIWORAs typically were associated with occult disk injuries and occult perivertebral hemorrhage, but not with fractures. Because of apart mentioned reasons about disk dislocation, occult disk herniation or spontaneously reduced subluxations could cause spinal cord compression, but are not evidentiated at PMCT.

A specific pitfall about SCIs and SCIWORAs is represented by postmortem positional changes which can lead to a reduction of subluxations, also associated with reduced blood circulation caused by the death [26].

10.3 PMMR vs. PMCT vs. Autopsy

PMCT and PMMR are equivalent or superior to conventional autopsy in identifying spine fractures to conventional autopsy. PMCT can identify upper cervical spine injuries, with a good agreement with autopsy, but cranio-vertebral dislocations are better identified with autopsy [20, 27].

10.3.1 Chest and Abdomen Blunt Injury

Chest blunt injury is usually associated with injuries in other body parts. They are caused by different and combined mechanism such as a direct impact, compression, and deceleration.

A direct compression of chest causes ribs and sternal fractures. Typical fracture patterns depend on the site of compression: sternal and anterolateral rib fractures are due to anterior compression; posterior rib fractures are due to posterior compression, and a lateral compression causes costochondral disruption. Multiple ribs fractures are generally associated with hemothorax and pneumothorax, lacerations and contusion of the lungs and the heart. Mechanical heart lacerations are usually associated with injury to other structures of the chest. The causative force is typically applied to the anterior precordium. Due to its position between the sternum and the thoracic vertebrae, the heart is exposed to any sudden impact on the sternum and to compression forces applied to the chest. High energy blunt traumas (injury severity scores—ISS) can lead to different types of cardiac injury such as valve or myocardial contusions, cardiac rupture, and aortic lacerations with hemopericardium. These lesions are usually associated with a high mortality rate either by hemorrhagic or arrhythmic complications. The incidence rate of cardiac injury after blunt chest trauma in postmortem studies is reported between 14% and 20%. Cardiac lacerations are rare and usually fatal.

Heart lacerations may involve the right and left atria, the right and left ventricles, the atrial septum, the interventricular septum as well as the intrapericardial portion of the superior or inferior vena cava, the pulmonary veins, the atrioventricular valves, and their chordae tendineae. The rupture of interventricular septum with or without other cardiac injuries after blunt thoracic trauma in car accidents is rare as reported in the literature. The severity and degree of injuries depends upon the phase of the cardiac cycle at the time of injury. Late diastole or early systoles are periods of increased vulnerability because the chambers are full and the valves are closed. Autopsy studies have shown that the right ventricle is most frequently ruptured, followed by the left ventricle, right atrium, intraventricular septum, left atrium, and inter atrial septum in decreasing frequency (Figs. 10.8 and 10.9).

Possible mechanisms of laceration include a direct blow to the chest, compression of the heart through bidirectional forces between the sternum and the spine during early systole, with the ventricular cavity filled and the atrioventricular valves closed, deceleration or rapid rotation with fixation of the great vessels, transmission of high hydraulic venous pressure following compression of the abdomen or extremities and rupture of the myocardium by a fractured rib [28, 29].

Fig. 10.8 A 40-year-old Caucasian woman died in a traffic accident. The woman wasn’t seat-belted in the front passenger seat. At autopsy the anterior surface of the heart shows two transmural lacerations: the first cm 3 × 2 in size, located on the interventricular sulcus 3 cm from the atrioventricular sulcus; the second cm 3 × 2.5 cm in size located on the margo obtusus cordis

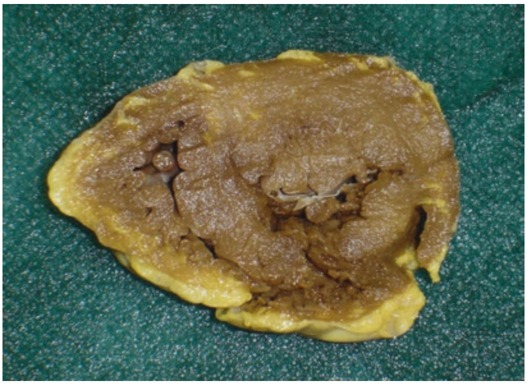

Fig. 10.9 The same case after parallel cuts made perpendicularly to the longitudinal axis, a laceration of the anterior side of the right and left ventricles and of the interventricular septum was observed

In all these injuries, the sudden great pressure applied to the chest seems to be the key factor in determining explosive cardiac laceration, frequently involving the roof of the atria and/or apex of both ventricular. Chamber or valvular

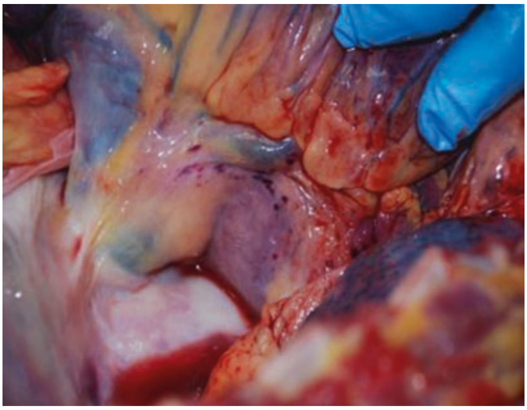

Fig. 10.10 On the posterior surface of the right atrium, punctiform ecchymosis were observed, specifically between the superior and inferior vein caval connection and the wall of the right atrium. The autopsy did not show external signs of thoracic trauma, no evident rib or sternum fractures

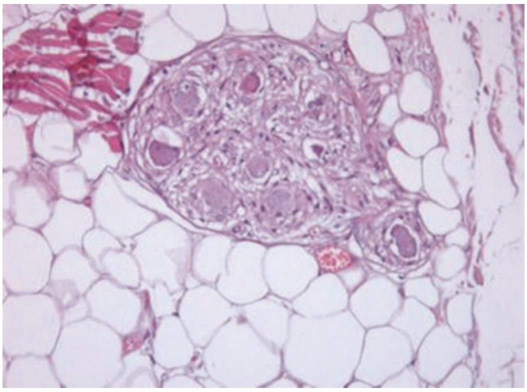

Fig. 10.11 In the atrioventricular conduction tissue, plurifocal petechial hemorrhagic infiltration of the interatrial septum involving the myelinic fibers in the contest of adipose tissue. E E 40×

rupture is more likely if impact occurs at end diastole, when the heart is maximally distended with blood. The severity of the lesion depends on the impact velocity and chest compression (Figs. 10.10 and 10.11).

- Blunt thoracic trauma can rarely cause coronary artery injury. Blunt trauma can result in occlusion of any of the coronary arteries or can lead to its rupture [30].
- Traffic accidents are, also, the most frequent causes of cardiac contusion (contusions) resulting from a direct blow to the chest. Rarely blunt cardiac contusion can result in cardiac conduction system injury leading to a fatal arrhythmia [31].

PMCT has a useful role in the detection of chest wall injuries such as hemothorax, pneumothorax, hemopericardium, pneumopericardium, pulmonary injuries, fractures of ribs and dorsal vertebras and the application of contrast medium does not much improve sensitivity of the technique in the recognition of chest wall lesions [4].

In some cases the cause of death can be also tension pneumothorax due to a chest wall trauma: in fact gas may induce pneumorachis and pneumocephalus which can be responsible of the death [32].

The presence of gas, as discussed, may be underestimated at conventional autopsy without using special techniques such as opening the body under water or using aspirometers. In these cases performing PMCT before autopsy can be useful to apply as the gold technique [11].

The presence of fracture of the ribs and thoracic spine with a flail chest and subsequent pneumothorax, pneumomediastinum, and hemothorax at PMCT may suggest exsanguination as the cause of death [17, 33].

At PMMRI hemothorax can be detected with high sensitivity and specificity, as reported in literature [6].

On PMMR images the typical pattern is characterized by sedimented corpuscular blood components at the bottom and a serous layer on top, due to the effect of gravity [6].

Moreover, in the same study conducted in 2012, it has been reported that pneumothorax was diagnosed with sensitivity of 100% and specificity and accuracy of 73%, while in ten cases was not detected at autopsy [6].

Aortic lacerations may occur in both head-on and side-impact crashes. Traumatic aortic rupture is the second most common cause of death in victims of blunt chest trauma from motor vehicle accidents [34]. Aortic rupture in blunt trauma results most commonly from sudden high speed deceleration or less frequently from chest compression. Other mechanisms involved in blunt aortic injuries might include compression of the vessels between bony structures, such as sternum and spine. The most common site of injury is the aortic isthmus [35, 36].

Specific signs of exsanguination include “vanishing aorta” sign, “hyperdense armored heart,” and “flattened heart,” which also correlate with cardiac tamponade [4].

Vanishing aorta refers to the collapse of the vessel, an important feature in fatal hemorrhage, but can be also seen in all the big vessels such as pulmonary arteries and caval veins. However it can also be seen in other causes of death due to a pressure loss from a decreased cardiac ejection [17].

Traumatic aortic rupture is not always detectable at unenhanced PMCT. It can be assumed when there is a big intrathoracic hematoma adjacent to the aorta without any fat plane in between. However PMMRI better recognizes aortic tears than in unenhanced PMCT, although at PMCT angiography an eventual “active” extravasation of contrast medium can be detected.

Overall sensitivity for ruptured aorta in postmortem CT and MRI together is between 75% and 100% [37].

Sometimes the presence of hyperdensities and nondependent air foci may be suggestive of thrombus formation [4].

Pulmonary embolism, as a secondary cause of death after trauma, is impossible to detect at unenhanced PMCT [17].

Myocardial ruptures are simply recognized at PMMR [6].

However aortic tears, despite the excellent soft-tissue image contrast of PMMR, are not easily recognized and localized in cases of exsanguination because of the collapse of the vessel lumen [6].

As in PMCT, the site of the lesion has to be suspected in case of perivascular and intramural hematomas.

The appearance of hyperdense aortic wall can be related to a contraction of the aortic wall, luminal loss of pressure and decreased attenuation of the lumen due to dilution of blood after massive infusion at resuscitation or sedimentation of the blood away from aorta. The possibility of atherosclerotic disease and the presence of intracardiac bypass or other devices can be useful at non-contrast PMCT in the recognition of the aorta after rupture within mediastinal bleeding [17] (Fig. 10.12).

Diaphragmatic injuries may occur rarely with blunt chest trauma. The rupture of the left side is more common than the right side probably because the right half of diaphragm is protected by the liver. The rupture of diaphragm is often associated with a herniation of abdominal organs and is generally associated with liver, spleen, and lungs blunt injuries.

Traumatic diaphragmatic hernias, characterized by the elevation of the diaphragm and abdominal organ herniation into the thorax, can be seen at PMCT. It could be very challenging to recognize at non-contrast PMCT the right side hernias: in fact the liver having the same attenua-

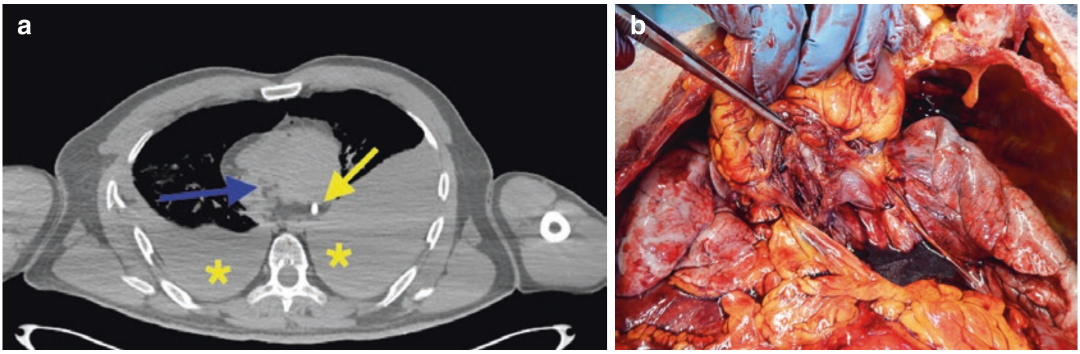

Fig. 10.12 (**a**) Unenhanced CT after a motorcycle accident shows the presence of a wide hematic pleural effusion due to the direct chest blunt trauma. It is also possible to recognize the presence of a cardiac bypass verified at autopsy (yellow arrow) and to conjecture a lesion of the posterior wall of the right atrium (blue arrow), demonstrated at autopsy. (**b**) Shows the traumatic laceration of the posterior wall of the right atrium

tion of hemothorax can make right diaphragmatic hernias missed. On the other hand, left-sided hernias are more simple to distinguish thanks to the natural contrast between the lung and the left-sided abdominal organs (stomach, bowel) [11].

10.4 Lung Lesions

However atelectasis can be easily recognized at contrast-PMCT because pulmonary tissue shows significative enhancement after administration of iodinated contrast medium [17].

The evaluation of lung parenchyma may include pulmonary contusions and lacerations. The direct damage to the parenchyma can be a cause of death through the formation of a pulmonary alveolo-venous fistula which leads to systemic arterial gas emboli. It has to be suspected in cases of open chest wall injuries and gas in the left side of the heart and systemic arteries without specific signs of putrefactive changes [38].

The evaluation of pulmonary parenchyma findings at PMCT can be difficult especially considering nonspecific signs associated with hypostasis which is not always simple to distinguish from pulmonary contusions or pulmonary hemorrhage or pulmonary edema with its different causes [38].

PMMR has an important role also in the detection of the lung parenchymal contusions and lacerations; however diagnostic value can be reduced by superimposition of postmortem alteration of lung tissue, as described for PMCT [6].

10.5 PMMR vs. PMCT vs. Autopsy

PMCT has a strong agreement with autopsy in the detection of ribs fractures [6].

Autopsy is superior in the identification of intrathoracic injuries, with the exception of pneumothorax and hemothorax. Moreover thoracic gas-related injuries can be missed with autopsy [39].

All studies state that autopsy was equal or superior to PMCT or PMMRI in identifying pulmonary injuries such as contusions and lacerations.

Several authors argue this to be the result of postmortem changes that render it difficult to distinguish between hypostasis, putrefaction, alveolar hemorrhage or even pneumonia on PMCT or PMMRI.

In concordance with other soft tissue and organ injuries, autopsy is the method that detects more cardiac and pericardial injuries.

Ross et al. investigated myocardial ruptures and found a sensitivity of 75% with PMMRI [6].

Schnider et al. conclude that PMCT sufficed in the detection of cardiac lesions [40].

Similar to fluid and gas in the pleural space, pneumomediastinum, hemomediastinum, pneumopericardium, and hemopericardium are often missed with autopsy. In contrast, PMCT detects even small amounts of fluid or gas in these injuries that are missed at autopsy [33].

Moreover, mediastinal shift remains undetected at autopsy in many cases [20, 33].

10.6 Abdomen

Blunt force applied to the anterior or lateral surface of abdomen can lead to lacerations of abdominal organs such as liver and spleen.

Unenhanced-PMCT has a low sensitivity in the detection of solid abdominal organ injury. The sensitivity for detecting liver injuries is 53%, with even lower sensitivities for splenic and renal injuries [41].

However high grade of liver and splenic injuries are recognizable and characterized as low-attenuation regions within the liver, fractured liver and spleen, focal intrahepatic parenchyma gas bubble (to distinguish from portal veins or hepatic veins gas accumulation), perihepatic or perisplenic blood and hemoperitoneum [15, 41].

Also renal injuries are difficult to depict at unenhanced PMCT if there is no evidence of perirenal fluid or fat stranding or shattered kidneys [15].

Bowel injuries have to be suspected when significant pneumoperitoneum is evident and there is not a high grade of decomposition. In fact bowel distension, intramural air, and gastromalacia

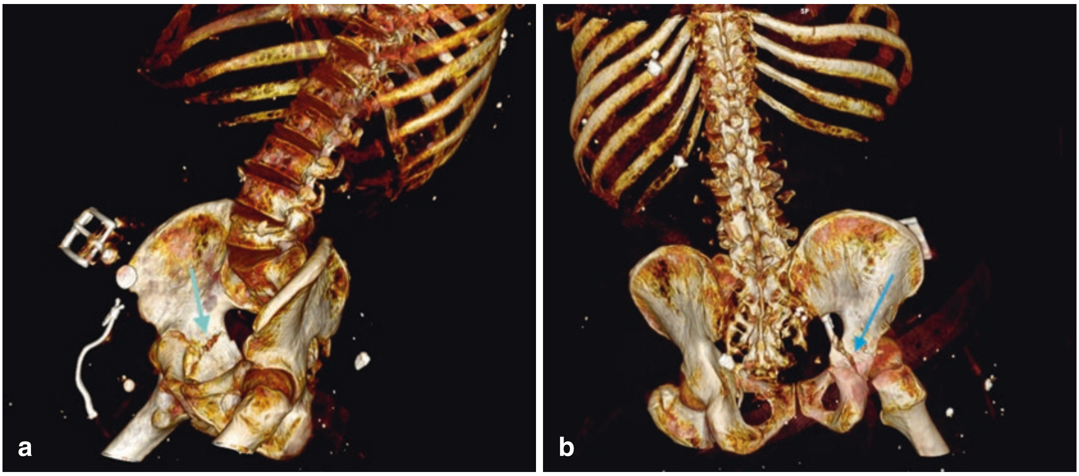

Fig. 10.13 Unenhanced CT of a young man ran over from a vehicle. The volume rendering reconstruction image highlights a length and direction of the iliac bone and of the sacro-iliac junction (**a** right; **b** left)

have to be suspected as normal postmortem changes [41].

On the other hand, the role of PMCT in the detection of lumbar spine and pelvic fracture is similar to bone's injuries in the whole body. Moreover, if pelvic fractures are associated with PMCT signs of exsanguination, these signs are high suggestive of potential cause of the death [11].

In the evaluation of abdominal organs lesions, PMMR can also be useful, especially for liver injuries. Both liver and splenic injuries have to be suspected if MRI shows fluid in the adjacent peritoneal space. For renal lesion PMMR has high specificity, while it is lower for pancreatic injuries.

In every case PMMR is very useful in the detection of peritoneal and retroperitoneal hemorrhages [6].

10.7 PMMR vs. PMCT vs. Autopsy

Autopsy remains superior to PMCT and PMMR in the detection of the injuries of organs and soft tissue of the abdomen.

PMCT and PMMR have a sensitivity of 100% in the identification of perihepatic and perisplenic fluid, although this finding does not adequately predict liver injuries [20, 41].

10.7.1 Pelvic Injuries

The bony pelvis suffers a variety of fractures and dislocations in severe trauma. The mortality is not caused by the pelvic fracture itself but is due to associated injuries such as disruption of the genitourinary and gastrointestinal system and laceration of great vessels [42].

The fracture of pubic symphysis or the posterior iliac spines and dislocation of both sacroiliac joints are due to an antero-posterior compression, as in running over by a vehicle wheel. An impact from the side may cause the superior and, rarely, the inferior pubic ramus with dislocation of the sacroiliac joint on that side [43].

The pelvic fractures are more easily detected by PMTC than conventional autopsy (Fig. 10.13).

10.8 Extremities

Post-traumatic alterations of the subcutaneous fatty tissue in fact is clearly visualized as homogeneous, well-defined accumulations of pooled liquid. Hemorrhages appeared as hypointense on T1-weighted sequences and hyperintense on T2-weighted sequences. Although a limit in the identification is the presence of extent subcutaneous fluid collection which may mask the post-traumatic findings in people who had been hospitalized and bodies that had begun to decompose [6].

Fractures of the extremities are easily recognized when 1–1.5 mm thin-section acquisition is performed, and high resolution images are reached through volume rendering and multiplanar reconstruction techniques. Moreover it is possible to define site and type of fracture and to visualize soft tissue injuries without a dissection required in autopsy to reach bones [11].

10.9 PMMR vs. PMCT vs. Autopsy

Skeletal injuries of the extremities are well detected at PMCT which also identify additional fractures missed at autopsy [11].

On the other hand, PMMR has a mixed sensitivities, from 40% for upper extremity fractures to 100% for lower extremity fractures.

However for hematomas in the extremities, PMMR revealed high sensitivity [6, 20].

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