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ORIGINAL RESEARCH ARTICLE

Use of magnetic resonance imaging and computed tomography in postmortem diagnostics

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ABSTRACT

Introduction: Given the heterogeneous nature and inherent complexity of forensic medical expertise, the expert (medical professional or related areas) must make the best use of the technical and technological tools at his disposal. Imaging, referring to the set of techniques that allow obtaining images of the human body for clinical or scientific purposes, in any of its techniques, is a powerful support tool for establishing facts or technical evidence in the legal field. **Objective:** To analyze the use of magnetic resonance and computed tomography in postmortem diagnosis. **Methodology:** information was searched in the databases PubMed, Science Direct, Springer Journal and in the search engine Google Scholar, using the terms "*X-Ray Computed Tomography*", "*Magnetic Resonance Spectroscopy*", "*Autopsy*" and "*Forensic Medicine*" published in the period 2008–2015. **Results:** MRI is useful for the detailed study of soft tissues and organs, while computed tomography allows the identification of fractures, calcifications, implants and trauma. **Conclusions:** In the reports found in the literature search, regarding the use of nuclear magnetic resonance and computed tomography in postmortem cases, named by the genesis of the trauma, correlation was found between the use of imaging and the correct expert diagnosis at autopsy.

Keywords: Diagnostic Imaging; X-Ray Computed Tomography; Magnetic Resonance Spectroscopy; Autopsy; Forensic Medicine

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1. Introduction

Forensic medicine or forensic medicine comprises the application of medical science to technically and scientifically support the administration of justice. As an institute, its governing body in the Colombian case is the Colombian Institute of Forensic Medicine, a state agency composed of professionals in the medical and related areas, in order to issue expert opinions that serve as technical evidence in the clarification of the facts[1].

Forensic medicine is mainly recognized for its work in the field of the practical application of forensic medical expertise, which covers a wide range of expertise from psychiatric or psychological, to postmortem applications, in determining the manner of death (suicide, homicide or accidental).

It is worth noting that 2.5% of mortality in the world is a consequence of violence, in its different expressions. In 2012, worldwide, there was a rate of 6.7 homicides per 100,000 inhabitants. However, the highest homicide rate occurs in the Americas region, with 28.5 per 100,000 inhabitants[2]. In Colombia, the FORENSIS 2015 report mentions that, for the year 2017, 24,681 violent deaths were reported, within which suicides together with traffic accidents constitute the first causes. Likewise, 273,511 forensic medical examinations were performed, where interpersonal and intrafamily violence accounted for 73.5% of the cases[3].

In this wide range, given the heterogeneous and casuistic nature of the activity, in order to carry out the expertise (1) in question, the expert must make the best use of the technical and technological tools at his disposal; for example, in the practice of autopsies, supporting his expert conclusions on the information given by the diagnostic images of the body under study[4–6].

Now, it is good to mention that the use of technological tools in clinical diagnosis is not confusing; on the contrary, each technological advance has brought with it the need for native developments in the field of medicine. For the particular case of imaging, since 1895 the study and use of radiology as a support to forensic medicine is documented; where, as expected, to the extent of emerging technologies, these have been studied, tested and incorporated in the field[7,8].

In this regard, the studies and clinical use of the images produced are not exclusive to any single.

This fact is reaffirmed with the medical applications of magnetic resonance imaging (MRI) in 1980, a period in which numerous studies and investigations were developed, of which the recognition of cells with abnormal growth (tumors), carried out exclusively with the use of MRI, stands out[7–9].

Of course, these tools are so powerful that they transcend the equipment for medical jurisprudence, and it is a reality that advances in imaging, especially in MRI, have led to its use in all types of activities and its postmortem use has been increasing; being a support in those autopsies where (by religion or others) the practice of invasive examinations is not allowed, capturing images of different organs of the body, illustrating its usefulness to issue a correct expert diagnosis of the cause of death[9–12].

In this dynamic of incorporating technological advances in the practice of autopsies, the *Virtopsy®* project was created[11,13], whose proposal offers a non-invasive way of examining cadavers, making use of imaging studies, including computed tomography (CT). This latest technology, capable of performing various image analysis processes, such as volume reconstructions or morphometric measurements, has been widely accepted by specialized institutions, due to its speed of diagnosis and the easy filing and recording system, allowing the transport of data collected from remote specialists, without manipulation of the samples. These same utilities have led to the popularization of the use of MRI/CT, becoming the main methodologies for the performance of postmortem examinations[14].

On the other hand, for Colombia during 2017 there was no research or documentation on the application of these imaging techniques in postmortem studies, a logical consequence, since these technologies entail high implementation costs, so much so that, even in the so-called "first world", not all large hospitals have their own CT, let alone an MRI unit[15]. Under this reality, priority is given to allocating both economic and operational resources, mainly to the health care of surviving citizens, and not for eventual use in the administration of justice.

Facing this reality, the country cannot be left behind in the technological advances that are taking place and leave aside the principles of justice, promoting impunity in cases that, due to their particularity, require the use of efficient techniques to clarify their motives. Hence the need to document cases in which such techniques were applied in postmortem studies, so that based on these records, their subsequent application can be achieved. With this intention, the present review work aims to analyze the use of MRI and CT in postmortem diagnosis, seeking to generate concern in professionals in the company of students of health sciences, and inciting an investigative awareness that is expected to promote further research for a future application of the techniques and their associated technologies in the Colombian territory.

2. Postmortem imaging

Postmortem studies are all those internal and external studies performed on a corpse to determine the cause of death[16]. Among them is the necropsy, which is the procedure that studies the morphological alterations of organs and tissues as a consequence of disease or any cause of death[17,18].

Under the definition of necropsy, MRI and CT, together with conventional autopsy, are tools whose function is to clarify the diagnosis, making possible the study of trauma or pathological findings, and even of vital ante-mortem reactions, being particularly useful in those cases of doubtful criminality; the images show with clarity and appropriate size any body structure, which means less invasion to the body under study[8,13,17].

The main importance of the use of any of these techniques for postmortem studies are the facilities that both provide, delivering reliable and three-dimensional data of body structures[17,19], guiding the collection of biological samples, also offering the possibility of creating a database for future research among other specialists, given the storage capacity of the information[12].

As a complement, imaging techniques can avoid unnecessary procedures, as well as reduce the number of autopsies (invasive procedures), which alter the body and make subsequent inspections more difficult[17,20]. In medical sciences, it is not to forget the human sense, so that relatives can see the corpse even after autopsy, the face is not subjected to dissection. With forensic imaging, the soft tissues and skeleton of the face can be examined nondestructively. If there is a need to take samples or fluids from the cadaver, these could be done in a guided manner with the above imaging techniques, thus offering less manipulation of the body by pathologists and technicians, and reducing the risk of infection for these personnel.

Another usefulness of these techniques is when, for cultural, religious or personal reasons, relatives do not allow an autopsy, but such an examination can be key to discovering the causes of death and, if necessary, to impart justice. Another utility of *post-mortem* imaging is the possibility of reevaluating a case by an expert of a specific subspecialty anywhere, anytime.

3. Magnetic resonance imaging

Magnetic resonance imaging (MRI) works based on the mechanical-quantum properties of atomic nuclei[21]. To carry out its function, it makes use of a set of powerful electromagnets, creating magnetic fields when current circulates through their coils; these fields stimulate the hydrogen atoms, which, once excited, return to their equilibrium position, producing a signal that is received by the transducers, then transformed into an electrical signal and subsequently converted into the physical image of the structure to be studied[22,23].

Multiple editing possibilities arise from the resulting image, and sequences can be used to remove, crop, enhance or highlight images. For example, using contrasts to remove (from the image) the fatty tissue and increase the intensity of the connective tissue to observe in a specialized sequence the knee joint, or suppress the water signal to increase the tissue signal and observe the brain parenchyma; the great advantage of MRI is that each sequence has a determined purpose as well as a structure, in order to observe the structure from different views of the scheme, concluding in the most accurate diagnosis[22–24].

This technique has the advantage of being able to clearly represent soft tissue lesions and pathologies. On the other hand, its use is not limited, it can be used to examine living victims of violent acts, since it is a non-ionizing method[11]. However, its benefits are not widespread, mainly due to its high costs, the need for high-field scanners for perinatal autopsy, the long time between examinations, the impossibility of directly showing calcium in bone tissue, as well as a very high risk of incidents or accidents if the safety standards in the imaging area are not met (example: missile effect, inadvertent introduction of patients with contraindications, burns)[8,25].

4. Computed tomography

CT is a technique that uses a combination of X-rays and computer systems to obtain a series of transversal images of a structure, which offer anatomical information in three dimensions. Thanks to this it is possible to study with precision, details of viscera, bones, muscle tissue, fat, among other structures[26,27].

The computed tomography equipment consists of a *gantry* or vertical body, which has a central hole, which contains an X-ray tube that rotates around the patient, a table or examination table, where the structure to be studied is placed, the *gantry* emits radiation that passes through the body or object, which are modified according to the absorption coefficient of the different tissues. These modified radiations are captured on the opposite side by solid or gaseous state detectors. The ionization produced by the X-rays in the detector molecules is converted into electrical signals that are transmitted to a computer, where they are transformed into digitized images at the operator's interface[28].

As advantages we can mention that the technique can detect and represent foreign bodies, fractures, gas, fluid accumulations and calcifications in large vessels. Likewise, its use through postmortem angiography allows the detection of ruptures or occlusions of blood vessels with smaller caliber[29]. Additionally, CT requires only a few minutes for its performance and this characteristic will allow a large number of cadavers to be analyzed[30]. However, it has limitations with respect to the evaluation of soft tissues and internal organs, since the densities of the tissues in the face of damage or pathology may present changes so small that they cannot be detected by the technique (for example: in the case of a subarachnoid hemorrhage, it would not be possible to know if the cause was due to aneurysm or arteriovenous malformation).

5. Methodology

A search for information was performed in the databases PubMed, Science Direct, Springer Journal and in the search engine Google Scholar, using the terms MESH: "Computed Tomography", "Magnetic Resonance", "Autopsy", "Postmortem" and "Forensic Medicine", published in the period 2008/01/01–2015/12/31, filtering the information by type of article where case reports, original research articles and reviews, published in English, were selected. Afterwards, an analysis of the titles, abstracts and reading of the articles available in their full version was carried out, to subsequently select 50. Additionally, other documents were added to expand the information for some topics, based on REFERENCES or PubMed search.

The case study, as a research methodology, is the study of the particularity and complexity of a singular case. This method is used when there is a special interest in the case itself, in order to understand its activity in important circumstances, always seeking in detail the interaction with its contexts[31]. Within this methodological framework, the following cases are derived:

5.1 Fracture of the cranial vault

MRI, by its own merit, is the best technique to observe the central nervous system. It offers unique images of the whole brain contour; and in turn, making use of multiple contrast sequences, it allows the enhancement of the pons, cerebrospinal fluid and the whole brain morpho-physiology[32-34].

Thanks to MRI, effluvium and bleeding in centralized regions such as the hippocampus, corpus callosum and choroid plexus can be observed in detail; it is also useful in the identification of traumas together with subdural and subarachnoid hemorrhages, as well as in probable damage to the ventricular system[35]. Therefore, it is the ideal tool to use in patients who have died from poly-trauma in traffic accidents, from blows with blunt objects or falls from great heights, also, of course, to observe the complexity of the damage and the factors that caused their death[36](**Figure 1**).

It should be emphasized that this technique does not completely replace the conventional autopsy (**Figure 1a**), but it is a powerful tool to visualize elements omitted by the human study; allowing three-dimensional reconstructions or axial slices, where the position and size of the lesion is easily observable (**Figures 1b** and **1d**); It also improves the understanding of masses circumscribed from the cavity that normally contains it, by a natural or accidental orifice (yellow arrows in **Figure 1c**), which is equivalent to determine physical magnitudes, such as distances, type of objects, among others.

5.2 Stab wound in the thoracic region

Wounds caused by firearms, sharp weapons and trauma due to accidents constitute a great challenge for the pathologist in charge of the necropsy, since they cause lesions in various tissues and organs, which cloud the diagnosis.

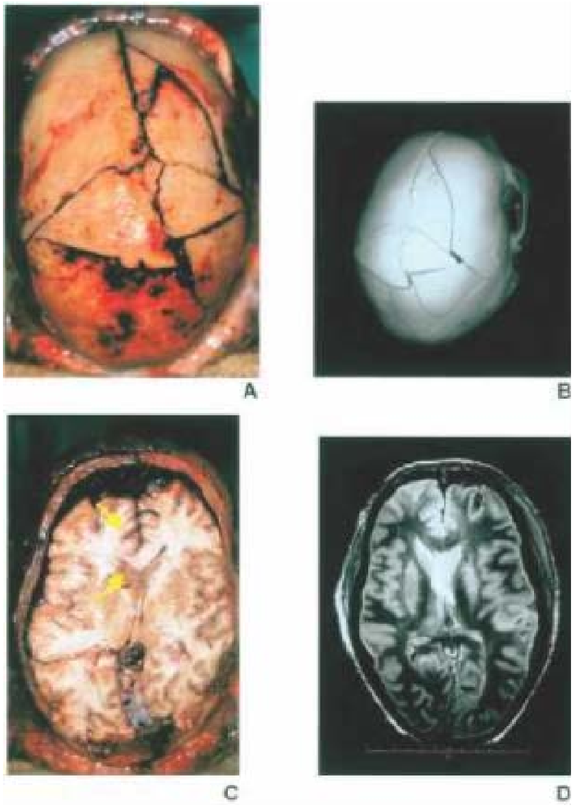

Figure 1. Fracture of the cranial vault in a 27-year-old patient due to a fall from a tree. (**a**): Autopsy image; (**b**): three-dimensional reconstruction of the bone table; (**c**): axial autopsy slice; (**d**): axial T2 MRI image.
Source: Taken from Thali *et al.*[13]

For Jackowski *et al.*[37], a critical case for the diagnosis makes its appearance in those wounds present in the thoracic region, given that in this region different structures essential for human life are located, any omission can lead to the undesired misdiagnosis, or no less serious, to establish idiopathic causes of death[38].

This situation contradicts the conventional autopsy, making it necessary to look for alternatives; with MRI it is possible to appreciate complex cardiopathies (for example: heart failure, endocarditis, perforations, mediastinal and cardiac contusions)[39,40]; and at the respiratory level, any type of traumatic lesion that causes pulmonary collapse, such as crushing, mechanical asphyxia, closed chest trauma, among others[40,41]. Likewise, it is possible to diagnose thromboembolism, pleural effusions, infectious processes (pneumonia, tuberculosis), trauma pathologies, neoplasms, hemothorax, pneumothorax and chylothorax[42], chronic diseases such as pleural and pulmonary mediastinal tumors and emphysema with pulmonary consolidations. Contrasting the resonance images, it is possible to appreciate the pulmonary parenchyma in every context and thus find the correct diagnosis[43,44].

The detailed image obtained by MRI, facilitates to observe the complete lesion trajectory and the adjacent damage in its path (**Figure 2c**), in which the lesion is shown in the cutaneous tissue, supported to a CT to perform the subsequent lesion route[44,45]. As mentioned, the contrast is an advantage of MRI (**Figure 2b**) affirming the myocardial tissue lesion of the autopsy (**Figure 2a**) with the appearance of intracardial clot; and at the same time lesion at vascular level is observed (**Figure 2d**).

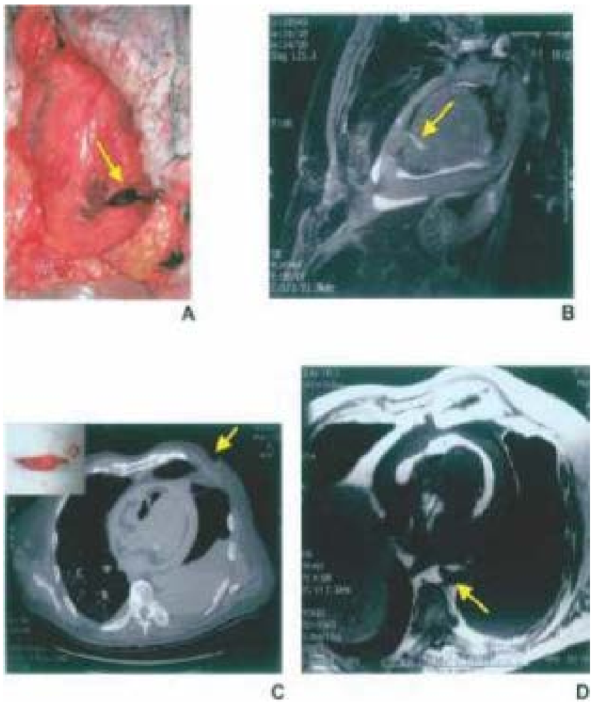

Figure 2. Patient who died from a stab wound located in the thoracic region. (**a**) Autopsy image; (**b**) MRI coronal section; (**c**) computed tomography and magnetic resonance imaging; (**d**) MRI axial section.
Source: Taken from Thali *et al.*[13]

5.3 Trauma caused by traffic accidents

The musculoskeletal system (basically composed of bones, tendons and muscle tissue), besides being responsible for adequate locomotion, serves as a framework and mechanical support for each of the internal structures. The application of MRI in the evaluation of this system helps to clearly identify any type of injury, thus knowing the type and magnitude of the damage caused[21]. Its importance is such that the mere observation of the articulations provides relevant information on the life span of the bodies under study, as well as on the pathologies and related medications that could produce deformations or articular changes. At the same time, detailing tendons, given their propensity to suffer rupture due to any type of blunt trauma, can be reflected in MRI. In turn, the muscle tissue, once affected, shows hematomas, lacerations and other damages in the MRI (**Figure 3**) which, when the autopsy is performed, reaffirm the results given by the image[46,47].

In another study, the results of the conventional autopsy were compared with those obtained using CT and MRI, in order to identify and evaluate the biomechanics of the trauma in the causes of death[48]. In one of the individuals under study, the 3D reconstruction by CT showed the fracture of the odontoid process (**Figure 4a**), while MRI showed the displacement of the spinal cord caused by the fracture (**Figure 4b**). In similar studies, the effectiveness of the diagnosis using postmortem CT was investigated with victims of traffic accidents, which presented injuries in the head, neck, thorax, abdomen and pelvis, finding that postmortem CT can detect or presume a diagnosis of fatal trauma at the time of determining the cause of death[49,50].

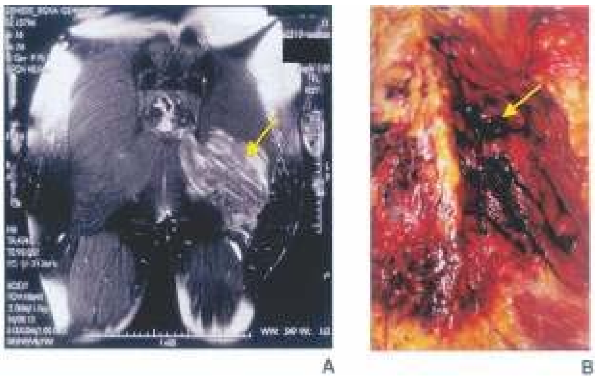

Figure 3. Patient deceased due to trauma caused by vehicular collision. (**a**) Coronal MRI slice, (**b**) autopsy image.
Source: Taken from Thali *et al.*[13]

5.4 Drowning

The gastrointestinal system is surrounded by solid organs, liver and pancreas, and hollow organs such as the stomach and intestines; irrigated by vessels ranging from the largest: aorta artery, vena cava crossing the entire digestive system, to the smallest, but no less complex blood vessels[46,51,52].

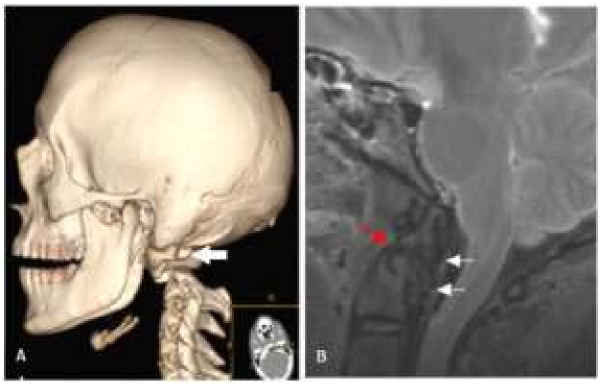

Figure 4. Deceased patient due to trauma caused by vehicular collision. (**a**) Computed tomography; (**b**) magnetic resonance imaging.
Source: Modified from Yen *et al.*[48]

The MR images of this system provide data for the finding of traumatic pathologies (lacerations, fissures and ruptures of hollow organs), caused either by gunshot wounds, stab wounds or blunt trauma (falls from great heights and blows)[53,54], as well as accidental ones such as drowning (**Figure 5**); where, making use of the enhancers, the abundant amount of liquid with solid parts in the stomach and duodenum is shown (**Figure 5b**) to then perform the autopsy (**Figure 5a**) where the first portion of the duodenum is seen to be clamped (arrows).

5.5 Intrahepatic gas

The presence of intrahepatic gas (GIH) is a frequent finding in postmortem CT in cases of non-traumatic death[55–57]. For this reason, investigations have been carried out on its detection by CT, to later confirm it by conventional autopsy. In one report, the location and occurrence of GIH was evaluated by multislice CT (MSCT) imaging in 208 non-traumatically deceased persons[56]. The location of GIH was rated on a scale of 0 to 3, with 0 being no gas occurrence at all; (1) gas only in the left lobe (**Figure 6a**); (2) gas in the left lobe and the anterior segment of the right lobe (**Figure 6b**); and (3) gas in the left lobe with the anterior and posterior segments of the right lobe (**Figure 6c**), finding that most cases had this finding in type 3 of the scale and that this correlated with the appearance of intestinal distension, and the period between cardiorespiratory arrest and the subsequent examination and autopsy.

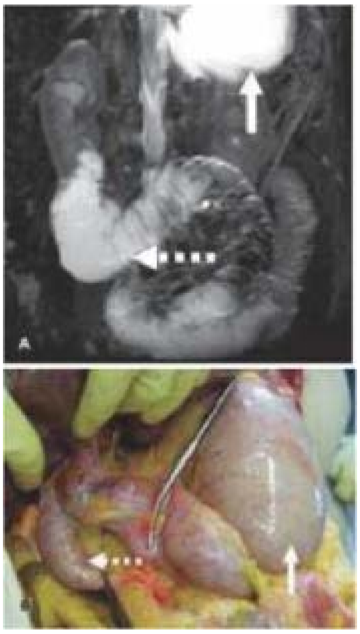

Figure 5. MRI and autopsy of individual deceased by drowning. (**a**) Coronal MRI slice; (**b**) autopsy image.
Source: Taken from Dirnhofer *et al.*

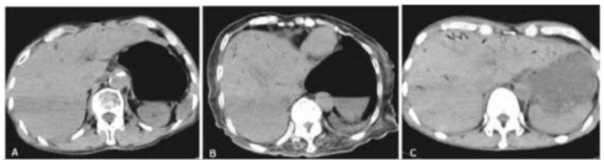

Figure 6. Multislice computed tomography of the abdomen, intrahepatic gas in the left lobe. **a**) type 1, (**b**) type 2, (**c**) type 3.
Source: Taken from Takahashi *et al.*[56]

5.6 Death due to pre-existing pathology

In the case of pre-existing pathologies, we studied the case of a 77-year-old woman who died suddenly after undergoing brain aneurysm surgery. The postmortem cranial CT scan showed that the hemorrhage due to the surgery disappeared without any complications, but the chest CT scan showed multiple metastatic lung tumors with abnormal masses in the bronchi (**Figure 7a**) and pleural effusion (**Figure 7b**), given these findings it is estimated that death occurred due to asphyxia caused by pulmonary metastasis and endobronchial tumors. Although a traditional autopsy was not performed, postmortem CT provided strong evidence for the detection of the cause of death, avoiding a judicial risk in the management of the hospital involved[58].

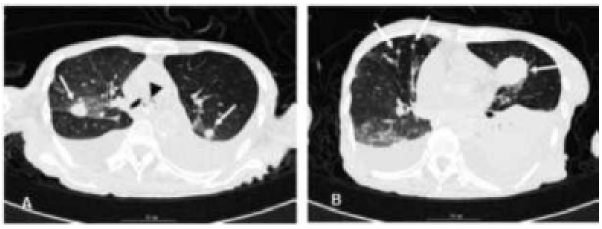

Figure 7. Chest computed tomography, patient 77 died of pulmonary metastasis. (**a**) Eidence of abnormal endobronchial mass; (**b**) vidence of bilateral pleural effusion.
Source: Taken from Takahashi *et al.*[58]

5.7 Identification of NN corpses (No *Name)*

CT has also been used for the identification of subjects, since it can detect characteristics of the bodies, such as implants, surgeries or old fractures[59]. It can be seen, for example, for the studies performed by Dedouit *et al.* on 35 bodies; of the 35 scans, ten revealed skeletal malformations, old fractures, or unconsolidated fractures in the neck of the right femur (**Figure 8a**); a fracture of the first cervical vertebra at the left pedicle level (**Figure 8b**); a lumbar spine with osteosynthesis material (**Figure 8c**); a calcification in the left thyrohyoid ligament (**Figure 8d**), bilateral isthmic spondylolisthesis of the fifth lumbar vertebra, and a thoracic vertebral angioma[60,61].

Figure 8. Computed tomography of possible skeletal malformations.(**a**) Uconsolidated fracture of the femoral neck; (**b**) fracture of the first cervical vertebra; (**c**) lumbar spine with osteosynthesis material; (**d**) thoracic vertebral angioma.
Source: Taken from Dedouit *et al.*[60]

Some skeletal anomalies were confirmed by police investigations: the deceased who had the osteosynthesis material had a past history of spine fracture and surgery, the subject who presented with left cervical pedicular vertebra fracture had a recent history of cervical fracture. With the exception of the evidence of the osteosynthesis material, none of the above findings are seen during conventional autopsy[60].

6. Conclusions

Postmortem imaging is not intended to displace or be a substitute for conventional autopsy, in fact, these techniques can increase the number of autopsies or change their focus, both medical and legal, broadening the spectrum of conventional autopsy, in turn enabling the collection of archival images for further forensic investigations.

With the above in mind, it is good to highlight the benefits of MRI for research in forensic studies, including better image definition, the ability to reduce or intensify the signal of any type of tissue, the possibility of performing 3D reconstructions for complete outlines of any region of the body, among others.

On the other hand, CT provides different degrees of freedom for the image, making it easier to establish a direct correlation with the radiological data already acquired, being useful when the individual under study presents artifacts in his body. Like MRI, the use of postmortem CT can detect or presume fatal trauma in the diagnosis of the cause of death after accidents or other fatal conclusions. So much so that, combined with angiography, peripheral vascular lesions in trauma, whether closed or open in nature, are more easily analyzed.

Of course, and despite the good receipt of its outstanding advantages, postmortem imaging lacks other diagnostic features such as color, texture or odor, which may be relevant, and would not be present in the images.

Another aspect to consider is how the interpretations of the findings found in the images will depend on factors such as the cause of death, normal postmortem changes, effects of cardiopulmonary resuscitation, among others. Therefore, clinical radiologists may be confused or misinterpret findings from cadaveric radiology, and this forces us to note that forensic radiology is not the same as applied clinical radiology.

Finally, there is another no less important dimension, referring to financial issues, since it is not recommended to generate synergies in hospital equipment, even though the same tomographs or resonators (which are used for patients in general) can be used in forensic work, as this could jeopardize the safety and health of people and facilities, leaving the need to set up forensic diagnostic imaging units under discussion.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Caballero C, Moreno H. Tratado de medicina legal: Jurists and medicine. 3rd ed. Bucaramanga, Colombia: Editorial UNAB; 1996.
2. Butchart A, Mikton C, Dahlberg LL, *et al.* Global status report on violence prevention 2014. Injury Prevention 2015; 21(3): 213.
3. Legal INdM, Violence GCdRNs. Forensis 2015. Datos para la vida. Colombia; 2016. p. 729.
4. Payne-James JJ, Stark MM. Clinical forensic medicine: History and development. In: Stark MM (editor). Clinical forensic medicine: A physician's guide. Totowa: Humana Press; 2011. p. 1–44.
5. Ludwig J. Postmortem Imaging Techniques. In: Waters BL (editor). Handbook of autopsy practice. Totowa: Humana Press; 2009. p. 99–103.
6. Medical-Legal Aspects. Radiological reporting in clinical practice. Milano: Springer Milan; 2008. p. 27–38.
7. Arce Mateos FP, Fernández Fernández FÁ, Mayorga Fernández MM, *et al.* La autopsia clínica (Spanish) [Clinical autopsy]. Electronic Journal of Autopsy 2009; 7(1): 10.
8. Flach PM, Thali MJ, Germerott T. Times have changed! Forensic radiology—A new challenge for radiology and forensic pathology. American Journal of Roentgenology 2014; 202(4): W325–W334.
9. Common Sense in Clinical and Preclinical Diagnosis. Radiological reporting in clinical practice. Milano: Springer Milan; 2008. p. 79–80.
10. Thali MJ, Jackowski C, Oesterhelweg L, *et al.* VIRTOPSY—The Swiss virtual autopsy approach. Legal Medicne (Tokyo) 2007; 9(2):100–104.
11. Tejaswi KB, Hari Periya EA. Virtopsy (virtual autopsy): A new phase in forensic investigation. Journal of Forensic Dental Sciences 2013; 5(2): 146–148.
12. Thayyil S, Chandrasekaran M, Chitty LS, *et al.* Diagnostic accuracy of post-mortem magnetic resonance imaging in fetuses, children and adults: A systematic review. European Journal of Radiology 2010; 75(1): e142–e148.

13. Thali MJ, Yen K, Schweitzer W, *et al.* Virtopsy, a new imaging horizon in forensic pathology: Virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI)—A feasibility study. Journal of Forensic Sciences 2003; 48(2): 386–403.
14. Stawicki SP, Aggrawal A, Dean AJ, *et al.* Postmortem use of advanced imaging techniques: Is autopsy going digital? OPUS 12 Scientist 2008; 2(4): 17–26.
15. Investor's Business Daily. MRI prices all over the map. 2015: A02.
16. Levy AD. Postmortem radiology and imaging postmortem radiology and imaging 2012 [Internet]. Available from: http://emedicine.medscape.com/article/1785023-overview.
17. Vogel H, Houck JASJSM. Postmortem imaging. In: Encyclopedia of forensic sciences. Waltham: Academic Press; 2013. p. 243–260.
18. Waters BL. Ensuring quality in the hospital autopsy. In: Waters BL (editor). Handbook of autopsy practice. Totowa: Humana Press; 2009. p. 3–9.
19. Lequin MH, Huisman TAGM. Postmortem MR imaging in the fetal and neonatal period. Magnetic Resonance Imaging Clinics of North America 2012; 20(1): 129–143.
20. Koch V. Methodenvergleich zwischen postmortaler CT und MRT Bildgebung in der forensischen Begutachtung (German) [Comparison of methods between postmortem CT and MRI imaging in forensic assessment] [PhD thesis]. Graz: Graz Medical University; 2009.
21. Jeffery AJ. The role of computed tomography in adult post-mortem examinations: An overview. Diagnostic Histopathology 2010; 16(12): 546–551.
22. Grover VP, Tognarelli JM, Crossey MM, *et al.* Magnetic resonance imaging: Principles and techniques: Lessons for clinicians. Journal of Clinical and Experimental Hepatology 2015; 5(3): 246–255.
23. Sederman AJ, Wang M. 4-Magnetic resonance imaging. Industrial Tomography: Woodhead Publishing; 2015. p. 109–133.
24. Nitz WR, Balzer T, Grosu DS, *et al.* Principles of magnetic resonance. In: Reimer P, Parizel PM, Meaney JFM, *et al.* (editors). Clinical MR Imaging. Berlin: Springer Berlin Heidelberg; 2010. p. 1–105.
25. Thayyil S, Chitty LS, Robertson NJ, *et al.* Minimally invasive fetal postmortem examination using magnetic resonance imaging and computerized tomography: Current evidence and practical issues. Prenatal Diagnosis 2010; 30(8): 713–718.
26. Panda A, Kumar A, Gamanagatti S, *et al.* Virtopsy computed tomography in trauma: Normal postmortem changes and pathologic spectrum of findings. Current Problems in Diagnostic Radiology 2015; 44(5): 391–406.
27. Cierniak R. Technical concepts of X-ray computed tomography scanners. In: X-Ray computed tomography in biomedical engineering. London: Springer London; 2011. p. 21–62.
28. De la Cerda Romero A. Equipos de tomografia computerizada (TAC) (Spanish) [Computed tomography equipment (CT)]. Digital Journal for Teaching Professionals 2009; 5.
29. Busardo F, Frati P, Guglielmi G, *et al.* Postmortem-computed tomography and postmortem-computed tomography-angiography: A focused update. La Radiologia Medica 2015; 120(9): 810–823.
30. Brough A, Morgan B, Rutty G. Postmortem computed tomography (PMCT) and disaster victim identification. La Radiologia Medica 2015; 120(9): 866–873.
31. Stake RE. Investigación con estudio de casos (Spanish) [Case study research]. Sage Publications; 2000.
32. Thayyil S, De Vita E, Sebire NJ, *et al.* Post-mortem cerebral magnetic resonance imaging T1 and T2 in fetuses, newborns and infants. European Journal of Radiology 2012; 81(3): e232–e238.
33. Zhang Z, Liu S, Lin X, *et al.* Development of fetal cerebral cortex: Assessment of the folding conditions with post-mortem Magnetic Resonance Imaging. International Journal of Developmental Neuroscience 2010; 28(6): 537–543.
34. Pedraza S. Usefulness of magnetic resonance imaging in traumatic brain injury. Medicina Intensiva 2013; 37(6): 373–374.
35. Yushkevich PA, Avants BB, Pluta J, *et al.* A high-resolution computational atlas of the human hippocampus from postmortem magnetic resonance imaging at 9.4 T. Neuroimage 2009; 44(2): 385–398.
36. Colleran GC, Moynagh MR, Tavernaraki K, *et al.* Whole-body magnetic resonance imaging: Emerging applications. Seminars in Musculoskeletal Radiology 2010; 14(1): 57–67.
37. Jackowski C, Christe A, Sonnenschein M, *et al.* Postmortem unenhanced magnetic resonance imaging of myocardial infarction in correlation to histological infarction age characterization. European Heart Journal 2006; 27(20): 2459–2467.
38. Bisset RAL, Thomas NB, Turnbull IW, *et al.* Postmortem examinations using magnetic resonance imaging: Four-year review of a working service. British Medical Journal 2002; 324(7351): 1423–1424.
39. Jackowski C, Warntjes MJB, Berge J, *et al.* Magnetic resonance imaging goes postmortem: Noninvasive detection and assessment of myocardial infarction by postmortem MRI. European Radiology 2011; 21(1): 70–78.
40. Ruder TD, Paula P, Hatch GM, *et al.* Science into practice: Post-mortem imaging provides conclusive evidence in a non-suspicious death. Journal of Forensic Radiology and Imaging 2014; 2(2): 80–84.
41. Taylor AM, Sebire NJ, Ashworth MT, *et al.* Postmortem cardiovascular magnetic resonance imaging in fetuses and children: A masked comparison study with conventional autopsy. Circulation 2014; 129(19): 1937–1944.
42. Rosales Uvera SG, Morelos Guzmán M, Vázquez Lamadrid J. Cor triatriatum dexter: Uso de

resonancia magnética cardiovascular en su diagnóstico a propósito de un caso (Spanish) [Right triatriatum heart: Use of cardiovascular magnetic resonance in its diagnosis, apropos of a case]. Revista Mexicana de Cardiología 2012; 23: 12–16.
43. Narin B, Arman A, Arslan D, *et al.* Assessment of cardiac masses: Magnetic resonance imaging versus transthoracic echocardiography. Anadolu Kardiyoloji Dergisi 2010; 10(1): 69–74.
44. Breeze AC, Jessop FA, Set PA, *et al.* Minimally-invasive fetal autopsy using magnetic resonance imaging and percutaneous organ biopsies: Clinical value and comparison to conventional autopsy. Ultrasound in Obstetrics & Gynecology 2011; 37(3): 317–323.
45. Peschel O, Szeimies U, Vollmar C, *et al.* Postmortem 3-D reconstruction of skull gunshot injuries. Forensic Science International 2013; 233(1–3): 45–50.
46. Patowary A. Virtopsy: One step forward in the field of forensic medicine. Journal of Indian Academic of Forensic Medicine 2008; 30(1): 32–36.
47. Cha JG, Kim DH, Paik SH, *et al.* Utility of postmortem autopsy via whole-body imaging: Initial observations comparing MDCT and 3.0 T MRI findings with autopsy findings. Korean Journal of Radiology 2010; 11(4): 395–406.
48. Yen K, Sonnenschein M, Thali MJ, *et al.* Postmortem multislice computed tomography and magnetic resonance imaging of odontoid fractures, atlantoaxial distractions and ascending medullary edema. International Journal of Legal Medicine 2005; 119(3): 129–136.
49. Shiotani S, Shiigai M, Ueno Y, *et al.* Postmortem computed tomography findings as evidence of traffic accident-related fatal injury. Radiation Medicine 2008; 26(5): 253–260.
50. Flach PM, Ross SG, Bolliger SA, *et al*. Postmortem whole-body computed tomography angiography visualizing vascular rupture in a case of fatal car crash. Archives of Pathology & Laboratory Medicine 2010; 134(1): 115–119.
51. Filograna L, Bolliger SA, Ross SG, *et al.* Pros and cons of post-mortem CT imaging on aspiration diagnosis. Legal Medicine (Tokyo) 2011; 13(1): 16–21.
52. Sogawa N, Michiue T, Ishikawa T, *et al.* Postmortem CT morphometry of great vessels with regard to the cause of death for investigating terminal circulatory status in forensic autopsy. International Journal of Legal Medicine 2015; 129(3): 551–558.
53. Raux C, Saval F, Rouge D, *et al.* Diagnosis of drowning using post-mortem computed tomography—State of the art. Archives of Forensic Medicine and Criminology 2014; 64(2): 59–75.
54. Lo Re G, Vernuccio F, Galfano MC, *et al.* Role of virtopsy in the post-mortem diagnosis of drowning. La Radiologia Medica 2015; 120(3): 304–308.
55. Fischer F, Grimm J, Kirchhoff C, *et al.* Postmortem 24-h interval computed tomography findings on intrahepatic gas development and changes of liver parenchyma radiopacity. Forensic Science International 2012; 214(1–3): 118–123.
56. Takahashi N, Higuchi T, Shiotani M, *et al.* Intrahepatic gas at postmortem multislice computed tomography in cases of nontraumatic death. Japanese Journal of Radiology 2009; 27(7): 264–268.
57. Jackowski C, Sonnenschein M, Thali MJ, *et al.* Intrahepatic gas at postmortem computed tomography: Forensic experience as a potential guide for in vivo trauma imaging. Journal of Trauma 2007; 62(4): 979–988.
58. Takahashi N, Higuchi T, Shiotani M, *et al.* Multiple lung tumors as the cause of death in a patient with subarachnoid hemorrhage: Postmortem computed tomography study. Japanese Journal of Radiology 2009; 27(8): 316–319.
59. Lorkiewicz-Muszynska D, Kociemba W, Zaba C, *et al.* The conclusive role of postmortem computed tomography (CT) of the skull and computer-assisted superimposition in identification of an unknown body. International Journal of Legal Medicine 2013; 127(3): 653–660.
60. Dedouit F, Telmon N, Costagliola R, *et al.* New identification possibilities with postmortem multislice computed tomography. International Journal of Legal Medicine 2007;121(6): 507–510.
61. Dedouit F, Savall F, Mokrane FZ, *et al.* Virtual anthropology and forensic identification using multidetector CT. British Journal of Radiology 2014; 87(1036): 20130468.