Neuro MRI at the End (Necropsy)
Forensic / Research Indications

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Objectives

At the conclusion of this talk, participants should

1. be familiar with the main issues of forensic postmortem investigations
2. be able to identify those forensic indications where MRI / MRS of the brain and the skull can be useful
3. recognize the opportunities of a scientific cooperation between clinical and forensic medicine

Introduction

Forensic medicine is a specialized field in medicine taking care of all problems occurring in judicature which can only be solved by scientific methods and knowledge in medicine, biology, chemistry, and physics; thus, also by using radiological methods including MRI. While the arising questions may also concern living persons such as in criminal and sexual assault or child abuse, this talk will be limited to the investigation of postmortem cases.

Postmortem MRI of the whole body or body parts in situ involves many changes compared to the examination of living persons, and there are various methodological as well as organizational issues which need to be accounted for in MR examinations.

a) Temperature

After death the body cools depending on time since death, ambient temperature, the weight and stature, and the clothing of the body causing core temperatures at the start of an MR scan in a range between 4° and 36°C. During examination, temperature changes by warming are frequent. Temperature has an influence on relaxation times.

b) Postmortem interval

With increasing postmortem interval (time since death) metabolic changes and, possibly, changes in water content occur during autolysis of the first three days depending on ambient conditions. After that further decomposition of soft tissues is often associated with the formation of gas bubbles. The postmortem interval is associated with changes of the relaxation times and other MR characteristics such as diffusivity.

c) Metallic objects

Particularly in forensic postmortem MR examinations care must be taken as bullets and other foreign bodies cause artefacts and might be ferromagnetic. Additionally, in forensic cases usually no information on medical history including the presence of implants is available.

d) Wrapping and positioning of the body

Adequate wrapping of the body is essential not only for hygienic reasons but also to prevent artefacts from metal parts such as zippers. Correct positioning of the head can be difficult because of the body bag and rigor mortis, as well as severely injured bodies.

e) Movement

Obviously, no artefacts due to patient movement or due to physiological movement exist in postmortem examinations. However, the absence of circulation also limits the application of angiography or contrast enhanced examinations.

f) Scan time

Postmortem examinations are not restricted in duration. Additionally, they can be conducted off business times such as at nights or on weekends.

Forensic Indications

Neuropathology and neurotraumatology are highly relevant in forensic medicine as reflected by numerous statistics which rate intracranial injury as a main cause of death particularly in younger people. Today's gold standard for the forensic postmortem examination of the head and brain is standard routine autopsy according to current guidelines. In the last decade an increasing number of study groups started to belabor classical forensic topics such as traumatic alterations of the brain stem or cranial gunshot injury by performing postmortem CT and MRI scans [1-6]. The application of MR seems to be particularly advantageous as it offers a variety of modalities which can contribute to solve main forensic questions.

Manner of death

The manner of death is a classification of how the cause of death came about as for instance homicide, suicide, accident or natural death. For the differentiation of the manner of death not only a survey of all findings and injuries is important, but also the circumstances of the death including a reconstruction of the sequence of events. In blunt injury of the head a frequent question as to the manner of death is the differentiation whether the injuries were caused by a fall or if the person was hit by someone. MRI is optimally suited for the detection of all necessary findings including the superficial soft tissue injuries at the localization of the impact, lesions of skull, extra- and intra-axial hemorrhage as well as cerebral contusions. The distribution of the lesions with reconstruction of the impact axis, their extent, and their exact localization using 3D reconstruction allow in most cases a reliable evaluation of the manner of death.

Cause of death

The cause of death is the disease or injury that produces the physiological disruption in the body resulting in the death of the individual, e.g., a gunshot wound of the head causing disruption of the brain stem and, thus, immediate respiratory arrest. Respiratory arrest is the most frequent cause of death directly related to brain injury as also indirect trauma can cause extensive edema leading to herniation of the brain stem with respiratory arrest. However, MRI of the brain can also add evidence which points at other causes of death.

Applications of different MR modalities to evaluate the cause of death:

1. Anatomical MRI including T1-weighted spin-echo, T2-weighted spin-echo, T1-weighted gradient-echo, and T2*-weighted gradient-echo sequences is suited for the evaluation of intracranial hemorrhage, cerebral contusions, and diffuse axonal injury.
To evaluate the diagnostic accuracy of postmortem MRI in the detection of primary traumatic extra-axial hemorrhage a group of forensic neurotrauma cases has been compared to a group of non-traumatic controls [7]. Before autopsy in situ postmortem MRI of the head and for additional comparison cranial MSCT had been performed. Analysis of the detection of hemorrhagic localizations in the neurotrauma cases revealed that MRI was more sensitive than CT in the detection of subarachnoid hemorrhagic sites, whereas no significant difference resulted from the detection of epidural and subdural hemorrhagic localizations. The specificity of MR imaging for the detection of non-hemorrhagic epidural, subdural and subarachnoid localizations was significantly better than that of CT.
But not only the principal detection of hemorrhage is important for a forensic diagnosis of the cause of death, but also particularly in the brain stem the differentiation between primary and secondary traumatic brain stem findings. Generally, primary traumatic microbleedings can be differentiated from the secondary findings that occur due to increased brain pressure due to the trauma by their exact location, and by their association with other cranial traumatic findings such as contusion hemorrhages or lacerations, and fractures of the skull [6].

2. In a study (yet unpublished data) using diffusion-weighted imaging (DWI) in three groups of deceased subjects which had died of direct brain trauma, strangulation, and heart failure, respectively, the apparent diffusion coefficient (ADC) was significantly lower in mechanical and hypoxic brain injury than in brains from subjects having deceased from heart failure. Thus, DWI could be helpful in the diagnosis of the cause of death, particularly in cases without obvious head trauma and unclear circumstances of death.

3. In situ MR spectroscopy (MRS) offers the possibility of systematic and focused investigation of postmortem tissue changes allowing noninvasive and even repetitive analysis of multiple metabolites simultaneously. It can be particularly useful for the detection of disturbances on a metabolic and functional level, which to date is rather a diagnosis by exclusion. Care needs to be taken concerning the sensitivity of MRS is limited, depending on the substances of interest. However, the investigation of metabolic disturbances responsible for death is very difficult, and clinical references are not applicable,

as postmortem changes tend to obscure antemortem distinctive metabolic features rapidly. Examples of possible applications include the analysis of free amino acids in the brain to reveal functional importance of renal and liver disease [8, 9]. As metabolic abnormalities might be concentrated in certain brain regions, localized information on metabolite concentrations can be acquired.

Time of death

Standard forensic methods for the estimation of the time since death, i.e., the postmortem interval (PMI) are based on the cooling of the body and the appearance of livor and rigor mortis. However, these methods are limited to about 48 hours after death. Thus, there is a high interest in additional methods contributing to this problem.

Applications of different MR modalities to evaluate the time of death:

1. As MR parameters reflect tissue characteristics, they are most likely also correlated with time postmortem. T1 and T2 relaxation times were measured in porcine brain tissue samples up to 90 hours after death or operative excision while being stored at 8°C. While T1 values did not show any time dependence, T2 values decreased slightly during the examination interval [10].

2. Recent (yet unpublished) results using DWI in postmortem subjects revealed a correlation of the PMI with ADC values measured in different regions of the brain. With increasing PMI, postmortem ADCs in grey matter (GM) regions and in the overall brain were significantly reduced while there was no significant effect in white matter (WM). Thus, ADC could possibly be used as an indicator of the PMI.

3. As an alternative method particularly useful for the estimation of longer PMIs, non-invasive observation of alterations in brain metabolites using 1H MRS has been suggested [11-14]. Localized 1H MRS was used to follow brain decomposition in a postmortem sheep brain model at four different temperatures with repeated measurements up to 2100 hours postmortem. The simultaneous determination of 25 different biochemical compounds at each measurement allowed following the time courses of their concentration changes. Eight compounds showed a linear increase with a slope related to the respective temperature. Thus, the time courses of metabolite concentrations could be described by a single analytical function with PMI and temperature as variables. Metabolite concentrations determined from a single MR spectrum can be used, together with known ambient temperatures, to calculate the PMI of a body.

Research Indications

In the context of clinical medicine and radiology, scientific studies based on the evaluation of postmortem MRI in an interdisciplinary cooperation with a forensic or pathologic department is a great opportunity for all participants. The validation of findings such as morphologic characteristics, quantitative measurements or microstructural changes is difficult and invasive or simply not possible in living persons.

Two examples of a successful cooperation are given:

To validate the transverse relaxation rates R2 and R2* as the most frequently used surrogate markers for iron in brain tissue, iron concentrations were determined chemically following quantitative MRI in human postmortem brains in situ [15]. In the overall brain, both transverse relaxation rates showed a strong linear correlation with iron concentrations, while in white matter only R2* correlated linearly with iron concentration. Not reflected in the relaxation rates, chemical analysis revealed significantly higher iron concentrations in the left hemisphere than in the right hemisphere. R2* showed to be very sensitive to brain iron variations and able to depict differences in white matter, it was judged the preferred parameter for the assessment of iron concentration in vivo.

In an ongoing study traumatic changes in white matter are investigated by comparing a group of deceased subjects after brain trauma to a group of non-traumatic controls. As these changes can be visible on a microstructural level, histological examination such as axonal density and thickness of myelin sheaths can be used to validate changes in quantitative MR imaging associated with neuronal and axonal damage [16].

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