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ORIGINAL ARTICLE

Post-mortem CT and MR brain imaging of putrefied corpses

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Abstract
Introduction Putrefaction of the brain is a challenge to a forensic pathologist because it may lead to considerable organ alterations and restrict documenting reliable autopsy findings.
Objectives This study aims to present a new and systematic evaluation of possible benefits of post-mortem MR Neuroimaging (1.5 Tesla, sequences: T1w, T2w) in putrefied corpses in comparison to PMCT and autopsy.
Methods A post-mortem MRI brain examination was conducted on 35 adult, putrefied corpses after performing a whole body CT scan prior to a forensic autopsy. Imaging data and autopsy findings were compared with regard to brain symmetry, gray and white matter junction, ventricular system, basal ganglia, cerebellum, brain stem, and possible pathological findings.
Results At autopsy, a reliable assessment of the anatomical brain structures was often restricted. MR imaging offered an assessment of the anatomical brain structures, even at advanced stages of putrefaction. In two cases, MR imaging revealed pathological findings that were detectable neither by CT scans nor at autopsy.
Conclusions Post-mortem MR imaging of putrefied brains offers the possibility to assess brain morphology, even if the brain is liquefied. Post-mortem MR imaging of the brain should be considered if the assessment of a putrefied brain is crucial to the evaluation of a forensic autopsy case.

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Keywords Post-mortem imaging · Post-mortem MRI · Putrefaction · Brain · Forensic imaging

Abbreviations

MRI	Magnetic resonance imaging
PMMRI	Post-mortem magnetic resonance imaging
PMCT	Post-mortem computed tomography
PMI	Post-mortem interval
RAI	Radiological alteration index
T	Tesla
T2w	T2-weighted
T1w	T1-weighted
TR	Repetition time
TE	Echo time

Introduction

Putrefaction is a challenge to forensic pathologists because it may lead to considerable organ alterations and restrict the possibility of documenting autopsy findings. The brain is vulnerable to putrefaction because it usually discolors, softens, and liquefies at an early stage of decomposition. Therefore, a putrefied brain often defies specific diagnosis. Studies presenting post-mortem computed tomography (PMCT) findings of the brain have been published, especially highlighting potential diagnostic pitfalls [1]. Post-mortem magnetic resonance imaging (PMMRI) has been introduced to the field of forensic pathology and is mainly used to assess cardiac-related deaths and soft tissue injuries [2–5]. PMMRI studies of the brain were conducted mainly demonstrating the possibilities for depiction of traumatic brain findings and early post-mortem-related brain changes. [6–11]. Moreover, particular applications for PMMRI such as diffusion weighted imaging and brain tissue quantification showed to be feasible for estimating early post-mortem intervals and determination of cause of death in some cases [12–14]. Post-mortem MR Neuroimaging results in advanced putrefaction have been mentioned in the literature correlating autopsy, CT, and MRI findings [15–17]. However, those studies mainly focused on isolated cases with advanced putrefaction. Thus far, no systematic study demonstrating the potential benefit of an MRI examination of putrefied brains has been published. Therefore, the goal of this study was to present a new and systematic evaluation of possible benefits of post-mortem MR Neuroimaging (1.5 Tesla, sequences: T1w, T2w) in putrefied corpses in comparison to PMCT and autopsy.

Materials and methods

Study subjects

A total of 35 adult corpses (22 males, 13 females) were analyzed in a prospective study in the period from February 2014 until June 2015. The age at death ranged from 21 to 83 years (mean 56.1, standard deviation 17.5). Study inclusion criteria were external and internal signs of advanced putrefaction. Cases with intracranial metallic foreign bodies were excluded. Advanced putrefaction was determined when there were external findings, such as brown or green discoloration of the skin and the superficial veins, ablation of external skin layers, or vesicle formations of the skin, as well as tissue softening and putrefaction gas formations detected by PMCT. The internal state of putrefaction prior to autopsy was determined by the radiological alteration index (RAI) by Egger et al. defined by criteria observed in whole-body PMCT [18, 19]. Only putrefied corpses with a RAI over 50 were included in this study. The post-mortem interval (PMI) ranged from 3 days to several months. Table 1 includes information about the study cases regarding the circumstances of death, state of putrefaction (according to the RAI), and post-mortem intervals.

Ten control cases (seven males, three females; age ranging from 22–94 years, mean 45.8, standard deviation 20.3) were assessed according to the same criteria as the main study cohort. The control cases showed no relevant signs of external or internal putrefaction. The PMI in this group was 3 days or less. The RAI was 28 for all ten cases, meaning that no relevant putrefaction gas accumulations could be detected with PMCT. Eight cases were accidental deaths (intoxication, suffocation or pulmonary fat embolism due to trauma). One case was a natural death caused by sudden cardiac arrest, and one case was a suicidal death caused by intoxication. In addition, a group of five cases with pathological intracranial and/or intracerebral findings was included in this study (three males, two females; age ranging from 44–95 years, mean 64.6, standard deviation 22.1). The cases with intracranial findings showed no relevant signs of external or internal putrefaction. The PMI in this group was <1 day, and the RAI was 28 for all five cases. Two cases were accidental deaths caused by traumatic intracranial hemorrhage, and three cases were natural deaths caused by spontaneous, intracerebral mass hemorrhage.

PMCT and PMMR imaging/image analysis

The bodies were wrapped in an artifact-free body bag or a linen sheet for PMCT (Somatom Emotion 6, Siemens Medical Solution, Erlangen, Germany) and PMMRI scanning (Siemens Magnetom Symphony Tim 1.5 T, Erlangen, Germany). All subjects were scanned in supine position at temperatures ranging from 15.7 to 22.4 °C (mean 21.2 °C). PMCT scan parameters were as follows: 140 kV care dose; rotation time 1 s; kernel: J30s and J70h; slice thickness 0.75 mm; increment 0.5 mm. The following MR sequences were applied: T2 tse tra, T2 tse cor, T2 tse sag (23 slices each, 5 mm thickness, gap 1.5 mm, TR 5000 ms, TE 92 ms, number of samples acquired: 2), T1 se tra (23 slices, 5 mm thickness, gap 1.5 mm, TR 500 ms, TE 9 ms, number of samples acquired 2). Matrix 512 × 464, FoV 230/210. The total PMMRI examination time for all sequences was approximately 30 min. Both PMCT and PMMR image analyses were performed on a Leonardo workstation (Siemens, Forchheim, Germany) by a board-certified forensic pathologist with 7 years of experience in forensic PMCT and PMMR Neuroimaging. Intracranial gas accumulations, brain midline/symmetry, the Superior sagittal sinus, anatomical brain structures (ventricles, gray and white matter junction, basal ganglia, brain stem, and cerebellum), visible brain pathologies, and distinctive features were assessed in terms of being recognizable and/or allowing diagnosis. "Allowing diagnosis" was defined as either the possibility to discern an anatomical structure from its surroundings with certainty that a pathology which would be recognized in a non-putrefied brain can be excluded or the straightforward diagnosis of a pathological finding (Fig. 1a). "Recognizable" was defined as the possibility to discern an anatomical structure from its surroundings without the certainty that a pathology which would be recognized in a non-putrefied brain can be excluded (Fig. 1b).

The use of the image data for the present study was approved by the local ethics committee.

Autopsy

Autopsies were requested by the local authorities and performed by forensic pathologists immediately after PMCT

Table 1 Information about age, gender, cause and manner of death, PMI, and RAI of putrefied study cases

Case no.	Age (years)	Gender (m/f)	Cause/manner of death	PMI (days)	RAI
1	34	M	Unclear/unclear	7	58
2	59	M	Unclear/unclear	14	100
3	44	M	Unclear/unclear	30	85
4	78	M	Unclear/suicide	150	100
5	57	F	Heart failure/natural	7	85
6	48	F	Hypothermia/suicide	8	54
7	62	M	Unclear/natural	28	100
8	30	M	Drowning/accident	7	85
9	70	F	Unclear/natural	40	70
10	64	M	Chest trauma/accident	3	54
11	66	M	Cardiac arrest/natural	14	54
12	27	M	Drowning/accident	5	85
13	44	M	Hanging/accident	8	63
14	21	M	Drowning/accident	7	100
15	54	M	Intoxication/accident	10	100
16	60	F	Unclear/natural	6	100
17	75	M	Unclear/natural	14	70
18	53	M	Pericardial tamponade/natural	4	85
18	82	F	Pneumonia/natural	10	100
20	61	M	Unclear/natural	21	85
21	83	F	Unclear/natural	7	85
22	59	F	Unclear/unclear	3	65
23	33	F	Drowning/suicide	3	85
24	65	M	Unclear/natural	28	100
25	65	M	Unclear/unclear	45	100
26	15	M	Drowning/accident	6	100
27	65	F	Drowning/suicide	72	85
28	76	F	Unclear/unclear	17	85
29	62	M	Unclear/natural	10	85
30	62	M	Cardiac arrest/natural	10	80
31	70	F	Hypothermia/accident	30	54
32	34	F	Intoxication/accident	10	80
33	59	M	Unclear/unclear	20	71
34	51	F	Unclear/unclear	10	85
35	74	M	Unclear/unclear	30	100

The PMI given in days was estimated to be the most likely PMI for each case based on the characteristics of putrefaction, police information, and data obtained by forensic entomology

and PMMRI scanning according to an in-house standard autopsy protocol. After dissection of the scalp, the skull was opened with an oscillating saw. The brain was extracted, weighed, and analyzed for recognizability of the anatomical structures and the diagnostic features mentioned above. The putrefied cases were separated into two groups based on brain consistency presented at autopsy. Twenty-two cases were determined to be "softened" (Fig. 2a, b) and 13 cases were determined to be "liquefied" (Fig. 2c, d).

A histologic examination was not performed due to pronounced softening or liquefaction of the brain tissue in all cases.

Results

Softened brains: autopsy

In the "softened" group ($n = 22$), the main strength of the autopsy was the diagnostic evaluation of brain symmetry (possible in 100 % of the cases), cerebellum (possible in 100 % of the cases), and the Superior sagittal sinus (possible in 100 % of the cases). The diagnostic evaluation of the intracerebral structures, such as the gray and white matter junction (possible in 36 %, partially possible in 23 % of the cases), ventricular

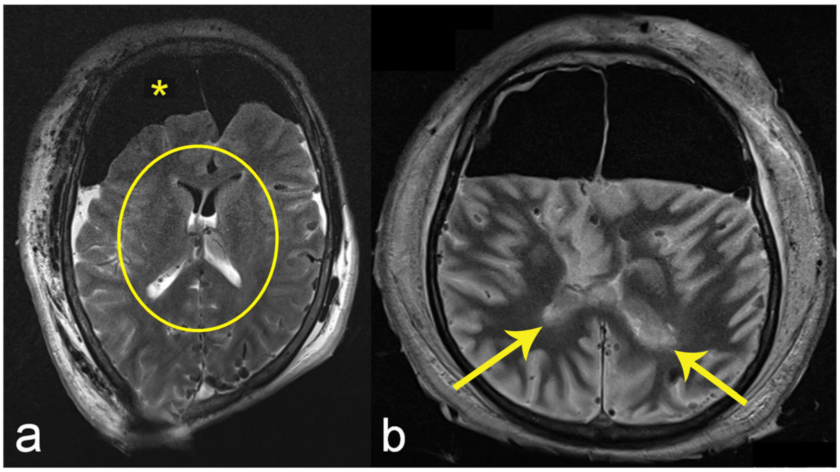


Fig. 1 Examples demonstrating the categories "allowing diagnosis" and "recognizable." **a** PMMRI (T2w, axial plane) of a softened brain. Note how the ventricular system (*circle*) depicts with minimal distortion due to intracranial putrefaction gas accumulation (*star*). Overall, the ventricular configuration in this case can be assessed with diagnostic certainty. In this case, the PMMRI depiction of the ventricular system was categorized as "allowing diagnosis". **b** PMMRI (T2w, axial plane) of a liquefied brain. Note how the dorsal horns of the lateral ventricles can be recognized (*arrows*), but how the ventricular system as a whole cannot be assessed with diagnostic certainty. In this case, the PMMRI depiction of the ventricular system was categorized as "partially recognizable"

system configuration (possible in 27 %, partially possible in 9 % of the cases), basal ganglia (possible in 46 % of the cases), and brain stem (possible in 50 %, partially possible in 5 % of the cases), was more limited. Some of the anatomical intracerebral structures were recognizable, but not with the certainty of a diagnostic evaluation (Table 2).

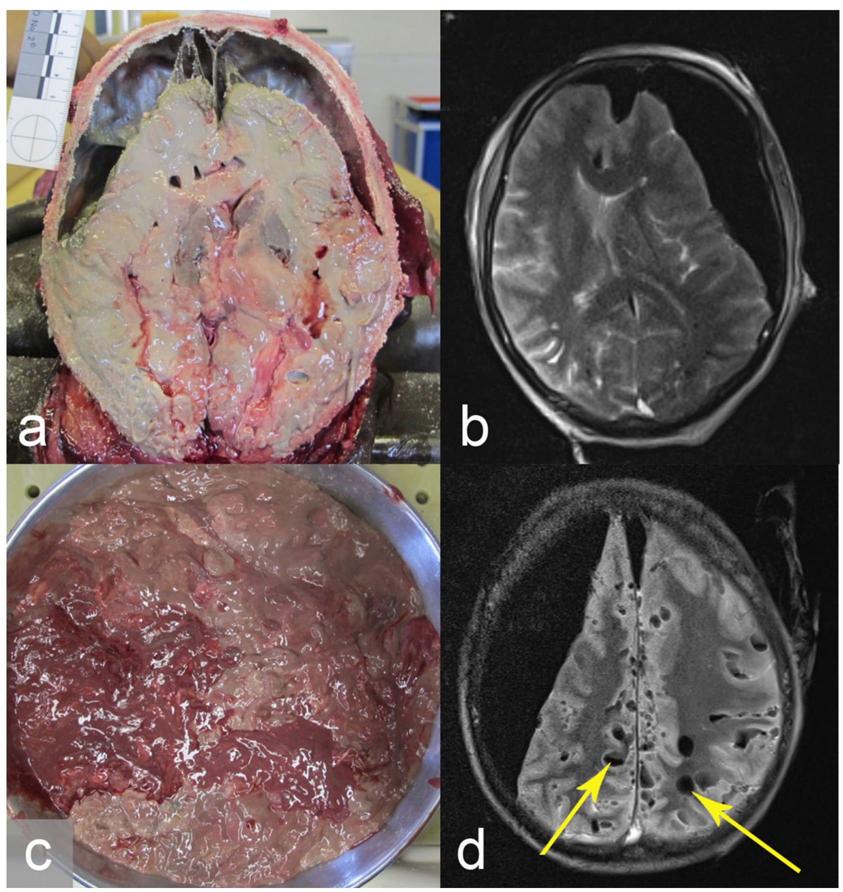
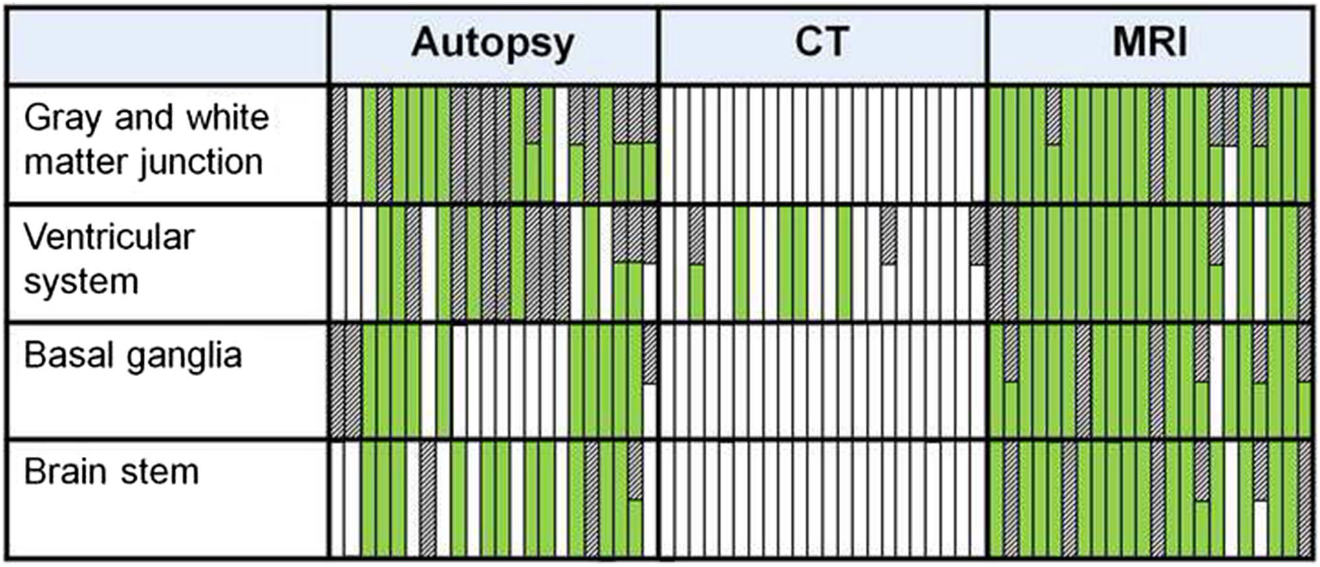


Fig. 2 Case examples. **a** Softened brain at autopsy. View from above. **b** PMMRI (T2w, axial plane) of the softened brain shown in Fig. 2a. Note that in PMMRI gray and white matter junctions are clearly more assessable than at autopsy. **c** Liquefied brain at autopsy. **d** PMMRI (T2w, axial plane) of the liquefied brain shown in Fig. 2c. The midline, gray, and white matter junction and part of the Superior sagittal sinus can be assessed. Large intracranial and/or intracerebral pathologies can be excluded. Note the putrefaction gas accumulations (*arrows*)

Table 2 Softened brains ($n = 22$); a representation of the recognizability (dashed bar) and possibility to formulate a diagnosis (green bar) when assessing intracerebral structures by autopsy, PMCT, and PMMRI



The white bar represents the finding "not recognizable". The half-dashed or half-green bar represents "partially recognizable" or "partially allowing diagnosis," respectively

Softened brains: PMCT

In the "softened" group ($n = 22$), the main strength of PMCT was the diagnostic evaluation of intracranial gas accumulations (possible in 100 % of the cases) and brain symmetry (possible in 91 % of the cases). Apart from the assessment of the ventricular system configuration (possible in 18 %, partially possible in 5 % of the cases), it was largely not possible to recognize intracranial structures with this method (Table 2).

Softened brains: PMMRI

In the "softened" group ($n = 22$), PMMRI allowed a diagnostic evaluation of most of the intracranial structures in most of the cases (Table 2). With diagnostic possibilities with regard to the assessment of the gray and white matter junction (possible in 77 %, partially possible in 7 % of the cases), ventricular system configuration (possible in 73 %, partially possible in 5 % of the cases), basal ganglia (possible in 68 %, partially possible in 18 % of the cases), and brain stem (possible in 68 %, partially possible in 5 % of the cases), PMMRI was the most helpful examination method in the "softened" group. It was also superior to PMCT and autopsy (Fig. 2a, b).

Liquefied brains: autopsy

In the "liquefied" group ($n = 13$), the only possibility of a diagnostic finding at autopsy was the assessment of the Superior sagittal sinus (possible in 77 % of the cases). None of the other abovementioned structures could be recognized (Table 3).

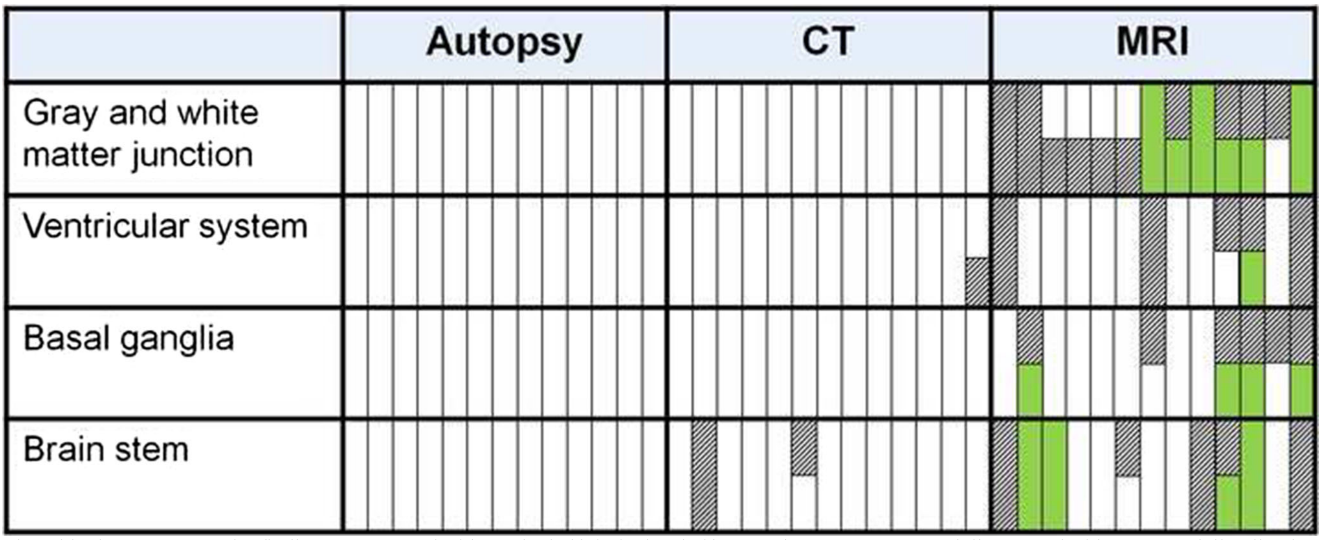
Liquefied brains: PMCT

In the "liquefied" group ($n = 13$), the main strength of PMCT was the diagnostic evaluation of intracranial gas accumulations (possible in 100 % of the cases) and brain symmetry (possible in 77 % of the cases). In two cases, it was possible to recognize some of the brain stem structures fully or partially. In addition, a partial recognition of the ventricular configuration was possible (Table 3). Apart from that, PMCT offered no assistance in the evaluation of the brain structures.

Liquefied brains: PMMRI

In the "liquefied" group ($n = 13$), PMMRI offered the possibility to assess some intracranial structures with diagnostic certainty (Fig. 2c, d). In three cases, the diagnostic evaluation of gray and white matter junctions was either completely (23 % of the cases) or partially (23 % of the cases) possible. Partial diagnostic evaluations were possible for the ventricular system configuration (4 % of the cases) and basal ganglia (31 % of the cases). The brain stem was diagnostically visualized in three cases (23 % of the cases). Table 3 shows that even if a diagnostic evaluation was not possible, PMMRI allowed visualization of some of the intracerebral structures in some of the cases. Two of the 13 cases presented with potentially pathological findings (Fig. 3a, b) which were not observed in PMCT scans and could not be verified or further studied at autopsy due to liquefaction.

Table 3 Liquefied brains ($n = 13$); representation of the recognizability (dashed bar) and possibility to formulate a diagnosis (green bar) when assessing intracerebral structures by autopsy, PMCT and PMMRI



The white bar represents the finding "not recognizable." The half-dashed or half- green bar represents "partially recognizable" or "partially allowing diagnosis", respectively. Note how PMMRI can offer minimal conclusions and sometimes diagnostic possibilities even in cases of advanced putrefaction

Control group: non-putrefied brains without pathological findings

In this control group ($n = 10$), no differences between the autopsy findings and PMMRI evaluation were noted. All assessed structures were diagnostically visualized using these two methods. PMCT allowed a diagnostic assessment of ventricular configuration and the Superior sagittal sinus. None of the other structures were sufficiently visualized by PMCT.

Control group: non-putrefied brains with intracranial and/or intracerebral hemorrhage

In this control group ($n = 5$), no differences between autopsy findings and PMMRI evaluation were noted. All the anatomical and pathological structures were diagnostically assessable in PMMRI and at autopsy (Fig. 3c). PMCT scan offered the possibility to determine the localization and extent of intracranial blood accumulations. Apart from that, PMCT presented the same restrictions in this group as in the aforementioned control group.

Discussion

The main and most surprising result of the present study was that putrefied brains, which presented as a liquefied mass at autopsy, seemed to preserve a large portion of their anatomical coherency as long as the skull remained intact. The preservation of structural integrity was visualized by PMMRI due to its specious ability to depict soft tissue. However, in some cases of the liquefied brains, the advancement of putrefaction and subsequent changes in temperature, pH value, and water content was reflected in the impossibility to recognize some

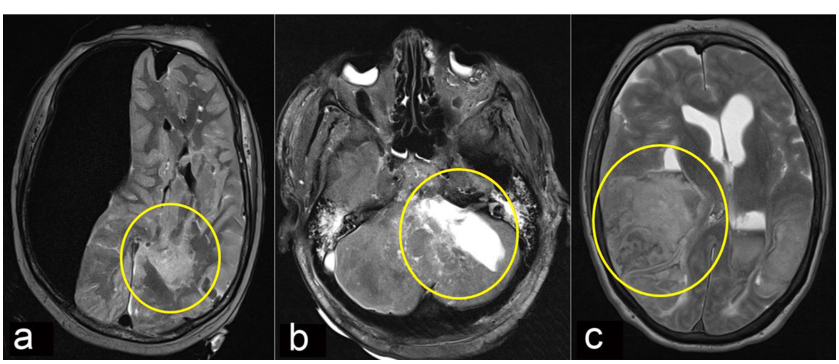


Fig. 3 PMMR imaging with intracerebral and intracerebellar findings. **a** PMMRI (T2w, axial plane) of a liquefied brain: hyperintense finding in the left hemisphere. **b** PMMRI (T2w, axial plane) of a liquefied brain: hyperintense finding in the left hemisphere of the cerebellum. **c** PMMRI (T2w, axial plane): right-sided intracerebral hemorrhage in one of the control group cases with a confirmed intracerebral mass hemorrhage

anatomical structures in PMMRI. Nevertheless, PMMRI was superior to both PMCT and autopsy especially when working with liquefied brains. The results of the present study indicate that superiority of PMMRI compared to PMCT and autopsy increases with advancing putrefaction and brain liquefaction. Yen et al. demonstrated that in fresh corpses PMCT and PMMRI were both satisfying for evaluation of intracranial hemorrhage compared to autopsy [16]. The present study indicates that diagnostic neuroimaging conditions may significantly change in advanced putrefied cases, and assessment of intracranial hemorrhage may only be possible with PMMRI in liquefied brains. Two of the 13 liquefied cases in the present study presented with potentially pathological PMMRI findings. According to the imaging data, a possible diagnosis could be the finding of intracerebral and intracerebellar hemorrhage (Fig 3a, b) in these cases. However, due to liquefaction, it was not possible to verify or refute this differential diagnosis at PMCT or autopsy. This illustrated that a general problem in PMCT and PMMRI of putrefied corpses seems to be the validation of possible relevant imaging findings at autopsy. Due to loss of structural integrity after opening the skull at autopsy, the liquefied brain tissue severely restrains any validation or confirmation of pathology. How possible relevant imaging findings could be extracted and further analyzed in the future remains subject to further studies. Possible reasons for the suspected inferiority of PMCT and autopsy for detection of hemorrhages compared to PMMRI may be relevant changes of brain tissue density and attenuation in PMCT before opening the skull and the total loss of structural brain tissue integrity in liquefied brains after opening the skull. If brains are only softened and not liquefied, PMCT and PMMRI may both be suitable for diagnosis of relevant alterations such as intracranial hemorrhage. As demonstrated by Aghayev et al., PMMRI and PMCT are feasible for detection of cerebellar tonsillar herniation in fresh corpses as a sign of severe brain edema [20]. The assessment of cerebellar tonsillar herniation was not a part of the present study. However, it may be assumed that cerebellar tonsillar herniation may be assessable both in PMCT and PMMRI of softened brains since the present study demonstrated that the structural integrity of the brain showed to remain more or less intact before opening the skull. Hereby, severe brain edema may be indirectly assessable even in putrefied softened brains.

The present study demonstrated that relevant signal changes of the regular anatomical brain structures occur due to putrefaction in PMMRI in softened brains. These findings supported the results of Kobayashi et al. who showed that signal changes in PMMRI brain may already occur relatively early in cases with less advanced putrefaction [12]. Based on the results of the present study, it can be assumed that brain lesions may be detectable in PMMRI as long as the anatomical brain structures remain differentiable in PMMR images. However, signal changes in PMMRI due to mere putrefaction may be misinterpreted as hemorrhages or other relevant findings such as tumor or contusion. Therefore, the PMMRI image reader of putrefied brains should always be aware of the pitfall of ambiguous signal intensity changes. Moreover, putrefaction of the brain may influence the minimal size of brain lesions still detectable in PMCT and PMMRI. Jones et al. analyzed neuropathological findings in brain trauma and correlated PMCT and PMMRI in fresh corpses [21]. Most hemorrhagic brain lesions with a diameter of more than 5 mm were visible in PMMR images, whereas the lesions were mostly underestimated when analyzed on PMCT images. Autopsy still remained the superior examination technique in their study. The results of the present study indicate that the detectability of smaller brain lesions of only some millimeters in size may decrease with advancing putrefaction. As discussed above, smaller sized signal intensity changes may be the cause of mere putrefaction and impossible to distinguish from actual pathology. Against this background, a larger pathology, such as a one-sided intracerebral mass hemorrhage, may be much easier to confirm in PMMRI of liquefied brains than considerably smaller lesions. In any case, it is safe to assume that PMMRI may still remain superior to autopsy and PMCT for detection of smaller sized brain lesions.

Several studies demonstrated that detection of intracranial gas accumulations is a benefit of PMCT and PMMRI whereas autopsy completely fails in that regard [6–9]. The results of the present study indicate that diagnosis of intracranial gas accumulations is the only parameter where PMCT remains superior to PMMRI in cases of advanced putrefaction.

Yen et al. demonstrated that diffusion tensor imaging may yield information about white matter tract integrity in the traumatized brain stem [22], a finding which could be correlated with autopsy findings. Scheurer et al. showed that diffusion weighted and diffusion tensor MRI can provide valuable information in forensic medicine regarding PMI and cause of death assessment [13]. While in fresh corpses these MR sequences showed to be able to provide relevant information, it can be expected that they are not feasible in putrefied brains due to damages of microstructural brain integrity. Hence, diagnosis on putrefied brains may be limited to conventional T1 and T2 weighted MR sequences.

Limitations

The present study has noteworthy limitations:

There was only one observer assessing CT and MR images. Therefore, no interobserver variability was tested.

The influence of temperature changes on PMMR image quality was not investigated. Previous work demonstrated that image quality in PMMRI may be altered due to different and particularly low corpse temperatures [3, 8, 14, 16]. In the present study, the observed temperature range between corpses was 7 °C at maximum and the mean temperature was 21.2 °C. At these temperatures, image quality was generally good and with sufficient grey value contrast. However, in cases with lower body temperatures, image quality and recognizability of brain structures may be significantly altered.

Conclusions

Post-mortem MR imaging of putrefied brains offers the possibility to assess brain morphology, even if a brain is liquefied. The execution of brain PMMRI should especially be considered if the assessment of a putrefied brain is crucial to a forensic autopsy case evaluation.

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