Analysis of magnetic iron compounds in the human brain: A Comparison of tumor and hippocampal tissue

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Introduction

Since magnetite (Fe_3O_4) has been discovered in the human brain in 1992, its formation and distribution are still an open issue. It has been reported that excess iron accumulation can cause neurological and neurodegenerative diseases. Magnetite is considered to be a source of Fe^{2+}, which can provoke oxidative cell damage. Though the origin of magnetite in the brain is not known in detail, ferritin (an iron storage protein) is a likely canditate for a precursor. In the present study, low temperature and room temperature magnetic methods are used to identify and characterize magnetite and ferritin in a set of 12 hippocampi and 12 tumor tissues (meningiomas).

Isothermal Remanent Magnetization (IRM) acquisition

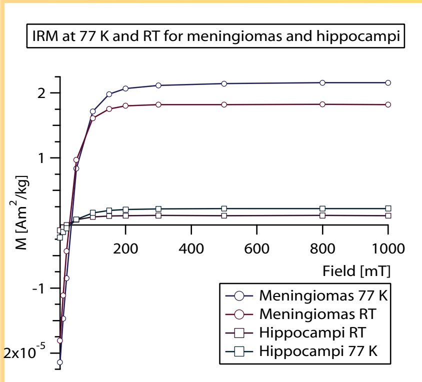

Fig. 1: Average IRM acquisition for meningiomas and hippocampi measured at 77 K and RT.

IRM acquisition was measured at 77 K and and RT on a 3-axis 2G SQUID cryogenic magnetometer for 24 samples. For both, meningiomas and hippocampi, the IRM acquisition shows a low coercivity phase that is saturated at 200-300 mT, indicative of magnetite/maghemite. The average saturation magnetization (M_S) at 77 K is 2.14×10^{-5} Am^2/kg for the meningiomas and 2.2×10^{-6} Am^2/kg for the hippocampi. The M_S at 300 K is 1.82×10^{-5} Am^2/kg and 1.12×10^{-6} Am^2/kg, respectively.

The coercivity of remanence (H_{cr}) was obtained from reverse field acquisition and average values are 34.5 mT for the meningiomas and 34.9 mT for the hippocampi at 77 K. These nearly identical values for H_{cr} suggest that the remanent phases are identical in the two different types of tissue.

Wohlfarths-ratio

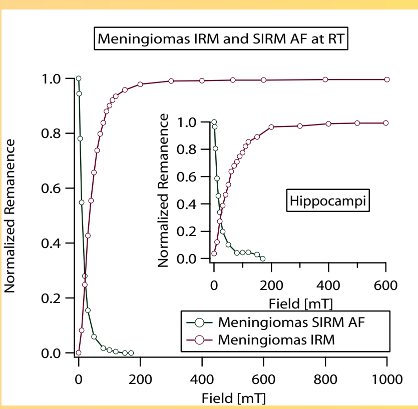

Fig. 2: Wohlfahrts-ratio determination for meningiomas and hippocampi at RT

Wohlfarths-ratio was determined by measuring IRM acquisition and SIRM AF demagnetization. Both curves show a steep increase or decrease and the Wohlfarths-ratio is low for meningiomas and hippocampi, which indicates interactions between the magnetic particles. The ratio for the hippocampi (0.32) is slightly higher, but the difference is not statistically significant from the meningiomas (0.26). This slight difference, however, may be due to the higher content of magnetic material in the meningiomas resulting in more clustering.

Induced magnetization

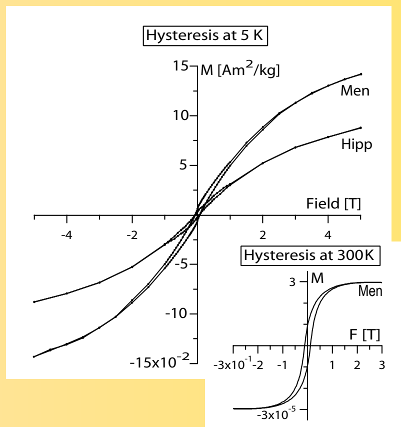

Fig. 3: Hysteresis measurements at 5 K for meningiomas (Men) and hippocampi (Hipp). The inset shows the hysteresis for a meningioma sample at 300 K corrected for all linear contributions.

Induced magnetization was measured as a function of field (hysteresis, Fig.3) and temperature (Fig.4) on an MPMS SQUID magnetometer on 8 samples of each tissue species. Hysteresis at 5 K reveals open loops with average H_c of 23 mT for the meningiomas and 34 mT for the hippocampi. At this low temperature, the antiferromagnetic core of the ferritin dominates the magnetic signal. The inset in Fig.3 shows the hysteresis of a meningioma at 300 K measured on an AGM at Princeton and corrected for all linear contributions. The open loop indicates a blocked low coercivity phase typical for magnetite/maghemite. For the hippocampi, no relevant hysteresis signal could be measured at RT.

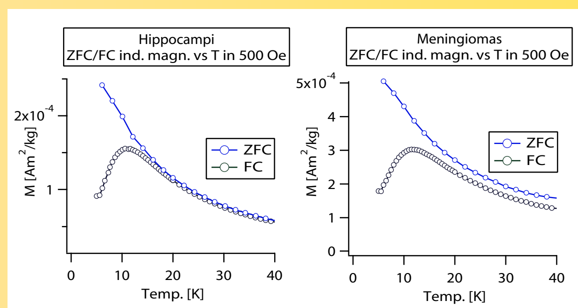

Fig. 4: FC and ZFC induced magnetization as a function of temperature measured in a 500 Oe field (Signal after subtraction of paramagnetic blood contribution). Left: hippocampi, right: meningiomas.

The ZFC curves show a maximum at 11-12 K, indicating the average blocking temperature (T_B) of the ferritin.The gap between the FC and the ZFC curve is very pronounced for the meningiomas and is due to a higher concentration of blocked magnetite. The curves were corrected for the nearly paramagnetic contribution of blood. Mean blood content was found to be five times higher in meningiomas than in hippocampi.

Tissue	M_S (77 K) x10^{-5} [Am^2/kg]	H_{CR} (77 K) [mT]	M_S (300 K) x10^{-5} [Am^2/kg]	H_{CR} (300 K) [mT]	% SP ($\Delta M_S/M_{S(77K)}$)	WF-ratio	Bloodcontent [mg/mg tissue$_{fd}$]	T_B [K]	H_C (5 K) [mT]	M_R (5 K) x10^{-4} [Am^2/kg]
Meningiomas	2.14(±1.27)	34.5(±6.3)	1.82(±1.60)	28.6(±5.0)	28(±24)	0.26(±0.02)	0.10(±0.07)	11.7(±0.5)	23(±15)	3.9(±3.3)
Hippocampi	0.22(±0.07)	34.9(±7.7)	0.11(±0.04)	26.2(±6.9)	37(±27)	0.32(±0.05)	0.02(±0.01)	10.9(±0.6)	34(±15)	2.4(±0.8)

Table I: Overview over mean parameters for both, meningiomas and hippocampi.

Conclusion

The remanent magnetic phases (magnetite/maghemite) are similar for both, meningiomas and hippocampi, as indicated by H_{cr} and IRM acquisition curves. Meningiomas show a higher blood content, a significantly higher remanent magnetic content; the mean Wohlfarths-ratio is slightly higher. Hippocampi with lower blood content have a relatively higher superparamagnetic content. Earlier studies have shown a higher ferritin concentration in tumor tissue compared to control tissu e. Our results show that there is a higher heme-iron and magnetite/maghemite content in tumor tissue as well.

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