HUMAN BRAIN MAGNETITE AND SQUID MAGNETOMETRY

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ABSTRACT

Most SQUID-based biomagnetic studies of the human brain have sought to measure magnetic fields generated by electrical activity. In this paper we report preliminary results of the first systematic survey of brain tissue using SQUID moment magnetometers. In an attempt to locate and quantify the amount and concentrations of ferromagnetic materials present, using these techniques, we have found evidence suggesting the presence of small single-domain crystals of magnetite with a concentration of 10 ppb in cerebellar and cerebral cortical samples of human brain. The presence of these particles in vivo could have an influence on both the recording of evoked magnetic potentials and on some of the spin echoes recorded with MRI techniques.

INTRODUCTION

It has been known for many years that crystals of biogenic magnetite (Fe_3O_4) are responsible for producing the magnetotactic behavior of bacteria[1,2], and magnetite has been linked recently to similar magnetic orientation of protoctists (eukaryotic algae)[3] and honeybees[4-6]. In the bacteria[7], protoctists[3], and salmon[8], a membrane-bound structure called a magnetosome contains the magnetite crystals which are aligned in chains. Magnetosomes produced by the magnetotactic bacteria have also been extracted and identified from sediments, and the geological record of these 'magnetofossils' now extends nearly 2 b.y. into Precambrian time[9], providing a geological constraint on the evolution of matrix-mediated biomineralization. Magnetite biomineralization may have evolved in bacteria as a result of the global change from reducing to oxidizing conditions. It is reasonable to suggest that the magnetotactic bacteria contributed their genetic ability through the process of serial endosymbiosis to the eukaryotic cells sometime during the mid-Proterozoic (~1.6 b.y. ago), and the recently-discovered magnetotactic protoctists are the extant co-descendants of these early eukaryotes. In turn, at least 3 major animal phyla known to biomineralize magnetite (mollusks, arthropods, and chordates) are probable descendants of these magnetotactic protoctists. Hence, we should not be surprised to discover magnetite biomineralization in a variety of higher organisms, including humans.

RESULTS FROM BRAIN TISSUES

Using SQUID moment magnetometry coupled with non-magnetic, clean-lab dissection techniques, we have discovered that frozen samples of both the cerebellum and cerebral cortex taken from elderly individuals can obtain Isothermal Remanent Magnetizations (IRMs) in the range from 10^{-7} to $10^{-6}Am^2/g$. These levels imply absolute concentrations of ferromagnetic material of about 10 ppb by volume, and provide the first direct evidence of the presence of ferromagnetic material within brain tissues. Paired IRM acquisition and Af demagnetization experiments are consistent with magnetite, and the IRM acquisition curve reaches a plateau in fields above 300 millitesla (mT); this has been confirmed on mineral extracts from solubilized tissue using electron diffraction. In these experiments, most of

the remanence is gained or lost in fields between 15 and 60 mT, which is typical for small single-domain crystals of biogenic magnetite on the order of 0.1 μm in size. (Similar crystals are known in a variety of bacteria, protozoans, and oceanic fish.) As an individual crystal of magnetite of this size will have a magnetic moment of about 5×10^{-16} Am^2, a remanence level of 10^{-6} Am^2/g as noted above implies the presence of over 10^6 crystals per gram of brain tissue. Acquisition experiments of Anhysteretic Remanent Magnetization suggest, however, that the particles are in highly interacting clumps, quite unlike those in bacteria, fish, or honeybees.

Although the biological function, if any, of these particles is unknown, enough of them may be present to account for the iron-correlated T1 and T2 spin echoes found in the magnetic resonance imaging (MRI) studies of similar brain tissues.

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