Magnetic Resonance Imaging Studies of Cigarette Smoking

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Abstract This chapter reviews studies that have applied magnetic resonance imaging (MRI) toward a better understanding of the neurobiological correlates and consequences of cigarette smoking and nicotine dependence. The findings demonstrate that smokers differ from nonsmokers in regional brain structure and neurochemistry, as well as in activation in response to smoking-related stimuli and during the execution of cognitive tasks. We also review functional neuroimaging studies on the effects of nicotine administration on brain activity, both at rest and during the execution of cognitive tasks, independent of issues related to nicotine withdrawal and craving. Although chronic cigarette smoking is associated with poor cognitive performance, acute nicotine administration appears to enhance cognitive performance and increase neural efficiency in smokers.

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1 Introduction

Nicotine dependence, usually maintained by cigarette smoking, is a psychiatric disorder that is characterized by compulsive drug-taking and withdrawal upon abrupt cessation of intake (American Psychiatric Association 1994). Although most smokers express a desire to quit, and about one-third of them attempt to do so each year (Centers for Disease Control and Prevention 2002), relapse is common. Only about 14–49% of those who initiate smoking cessation achieve abstinence after receiving nicotine replacement (Silagy et al. 2004), bupropion (Holmes et al. 2004), varenicline (Gonzales et al. 2006), or other combined treatments (Jorenby et al. 2006, 1999; King et al. 2006).

By the mid-1950s, there was sufficient evidence to support the hypothesis of a causal relationship between cigarette smoking and lung cancer; subsequent findings indicated the hazards of smoking to cardiovascular and pulmonary health (for a review see, Kluger 1997). A growing body of evidence, including results of non-invasive brain imaging studies, now suggest that the injurious effects of smoking may extend to the central nervous system. This chapter reviews magnetic resonance imaging (MRI) studies that aimed to clarify the neural correlates of nicotine administration and cigarette smoking. (Related information from nuclear medicine studies appears in the chapter by Sharma and Brody, this volume).

2 Studies of Brain Structure

Medical MRI physics and technology are described in several standard reference works (Kaacke et al. 1999; Weishaupt et al. 2006). Briefly, structural MRI is a non-invasive technique that can be performed repeatedly in vivo with minimal risk. To acquire MRI of the brain, the subject is positioned with his head inside a radiofrequency (RF) transmitter coil. Then subject and coil slide into the cylindrical bore of the scanner where a powerful magnetic field is maintained. The field splits the quantum mechanical energy levels of the hydrogen atom nuclei, or “protons,” in the brain such that a proton can absorb RF radiation broadcast from the transmitter and thereby be promoted to a higher energy state. After a time delay (“relaxation”), the proton releases the absorbed energy as an electromagnetic disturbance and is registered by a receiver coil that likewise surrounds the subject’s head. From the receiver signal, a crisp, 3D picture of the brain composed of 1 mm³ volume elements (“voxels”) is acquired in 5–15 min at clinical field strength (1.5 T) (Jacobs and Fraser 1994). The use of gradients, gradual variations in field strength along the x-, y-, and z-axes of the scanner, enable each voxel to be located in space. The intensity of the MR signal in the voxel is proportional to the density of protons but also varies with the rate of proton relaxation in the voxel. Since these properties vary with tissue type (e.g., gray matter, white matter, CSF), different tissues and different brain structures can be distinguished on the MR image. Advances in MRI have led to new efforts in elucidating the neural basis and sequelae of nicotine dependence (Table 1).