

CEREBRAL BLOOD FLOW DURING MEDITATIVE PRAYER:  
PRELIMINARY FINDINGS AND METHODOLOGICAL ISSUES<sup>1</sup>

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*Summary.*—Meditative practices typically require several coordinated cognitive activities. This study measured changes in cerebral blood flow during “verbal” based meditation by Franciscan nuns involving the internal repetition of a particular phrase. These results are compared with those we previously described in eight Buddhist meditators who use a type of “visualization” technique. Three experienced practitioners of verbal meditation were injected via IV at rest with 260MBq of Tc-99m HMPAO and scanned 30 min. later on a triple head SPECT camera for 45 min. Following the baseline scan, subjects meditated for approximately 40 min. at which time they were injected with 925MBq of HMPAO while they continued to meditate for 10 min. more (total of 50 min. of meditation). The injection during meditation was designed not to disturb practice. Subjects were scanned 20 min. later for 30 min. Counts were obtained for regions of interest for major brain structures and normalized to whole-brain blood flow. Compared to baseline, mean verbal meditation scans showed increased blood flow in the prefrontal cortex (7.1%), inferior parietal lobes (6.8%), and inferior frontal lobes (9.0%). There was a strong inverse correlation between the blood flow change in the prefrontal cortex and in the ipsilateral superior parietal lobe ( $p < .01$ ). This study on a limited number of subjects demonstrated the feasibility of studying different types of meditation with neuroimaging techniques, suggested that several coordinated cognitive processes occur during meditation, and also raised important methodological issues.

This study investigated changes in cerebral blood flow during different types of meditative practices to show the feasibility of applying neuroimaging techniques to the study of these complex tasks. There are only a few reports utilizing functional imaging techniques such as positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI), to study subjects performing meditative practices. PET imaging was utilized to measure changes in cerebral function in subjects undergoing Yoga meditative relaxation (Herzog, Lele, Kuwert, Langen, Kops, & Feinendegen, 1990-1991; Lou, Kjaer, Friberg, Wildschiodtz, Holm, & Nowak, 1999). Other studies evaluated yoga relaxation techniques using fMRI (Lazar, Bush, Gollub, Fricchione, Khalsa,

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& Benson, 2000) and our previously reported study of Tibetan Buddhist meditation using SPECT (Newberg, Alavi, Baime, Pourdehnad, Santanna, & d'Aquili, 2001). It is important to evaluate and compare changes associated with different meditative practices to help elucidate the underlying physiological mechanisms of such cognitive processes.

This preliminary report presents the SPECT data from three Franciscan nuns performing a practice called "centering prayer." Centering prayer requires the individual to focus attention on a phrase from the Bible or prayer over a period of time with the goal of "opening themselves to being in the presence of God." The nuns also describe a "loss of the usual sense of space." Centering prayer is similar to the type of Tibetan Buddhist meditation previously studied by our group in that attention is focused during the practice, but centering prayer is verbal while Tibetan Buddhist meditation is visual. Based upon our previously reported data, we tested three hypotheses. (1) Meditation would be associated with increased cerebral blood flow in the frontal lobes. (2) This increase would be associated with altered cerebral blood flow in the superior parietal lobe (associated with spatial perception) since subjects described alterations in their sense of space during meditation. (3) There would be decreased sensorimotor cerebral blood flow since subjects describe decreased sensory awareness and decreased motor activity.

#### METHOD

Three subjects performing verbal meditation (Franciscan nuns) and eight subjects performing visual meditation (Tibetan Buddhists) with no history or clinical evidence of medical or neuropsychological problems, or drug abuse, were recruited for this study. The methods for the study of the nuns are described here since those for the Tibetan Buddhists have been previously reported (Newberg, *et al.*, 2001). All three nuns were female while the Tibetan practitioners included four women and four men; each had performed more than 15 years of daily practice. On the study day, after obtaining informed consent (approved by the human Institutional Review Board), a room was set up in the hospital to function as a meditation room. An intravenous line (IV) was placed in one arm resulting in minimal discomfort that resolved prior to initiating the remainder of the study. Subjects rested in the room with their eyes closed and ears unoccluded for 10 min. at which time they were injected with 260 MBq of  $^{99m}\text{Tc}$ -hexamethyl propylene amine oxime (Amersham International, Arlington Heights, IL) and were scanned 30 min. later for 45 min. in a Picker-Prism (Picker Inc., Cleveland, OH) triple-headed gamma camera using high resolution fanbeam collimators. Images were obtained at  $3^\circ$  intervals on a  $128 \times 128$  matrix (pixel size 3.56 mm  $\times$  3.56 mm) over  $360^\circ$ . SPECT images were reconstructed (slice thickness was 4 mm with a spatial resolution of 8–10 mm), using filtered back-

projection, a Weiner post filter, and first order Chang attenuation correction.

Following this "baseline" scan, the subjects returned to the room to perform the prayer session. Subjects sat in a chair, their usual posture, and were allowed to utilize several religious books initially. Subjects had their eyes closed during the final 30 min. of the prayer session, including during the time of the second injection of the HMPAO so that the reading would not influence the scan findings. Outside noise was kept to a minimum and the door of the room was closed during the meditation. Subjects prayed for approximately 35 min. at which time they were injected with 925 MBq of  $^{99m}\text{Tc}$ -HMPAO from outside the meditation room while the subject prayed for another 10 to 15 min. (about 50 min. for the entire practice). Thirty minutes after injection the subject was scanned ("prayer" scan) for 30 min. Four nonmeditating control subjects were run through a similar test-retest protocol to demonstrate that no significant changes in cerebral blood flow would arise as the result of the imaging protocol.

Regional cerebral blood flow was measured in only a selected number of regions of interest from a previously validated template (Resnick, Karp, Treitsky, & Gur, 1993). The regions of interest examined were the inferior frontal, superior frontal, dorsolateral prefrontal, orbitofrontal, dorsal medial cortex, inferior temporal, superior parietal, inferior parietal, occipital, and sensorimotor areas, as well as the caudate, thalami, midbrain, cerebellum, and cingulate gyrus. Each region of interest was adjusted manually to achieve the best fit according to the atlas and copied directly onto the prayer scan. Counts in each region of interest were obtained for both baseline and prayer scans and normalized to the whole-brain blood flow. A percentage change was calculated by dividing the change by the mean value:  $\% \text{ Change} = 100 \times (\text{Prayer} - \text{Baseline}) / [1/2 \times (\text{Prayer} + \text{Baseline})]$ . Statistical parametric mapping was not utilized given it is a conservative approach and there is difficulty in yielding significant results with a small sample. Linear regression and Pearson correlations were generated to assess the association between blood flow changes in different regions and were confirmed using Spearman correlations (only Pearson correlations are actually presented).

#### RESULTS

Compared to baseline, the nuns performing verbal meditation showed increased cerebral blood flow in the prefrontal cortex ( $M=9.4$ ,  $SD=9.8\%$ ), inferior parietal lobes ( $M=11.9$ ,  $SD=4.2\%$ ), and inferior frontal lobes ( $M=10.1$ ,  $SD=9.3\%$ ). In comparison, we previously reported increased cerebral blood flow in the right thalamus, bilateral prefrontal cortex, inferior frontal lobes, and right medial temporal lobe in the Tibetan Buddhist meditators whose technique was visual. In the verbal meditation group, there was a sig-

nificant positive correlation between the change in cerebral blood flow in the right prefrontal cortex and that in the right thalamus ( $r = .87$ ,  $p = .03$ ). The change in cerebral blood flow in the prefrontal cortices showed a strong inverse correlation with that in the ipsilateral superior parietal lobe ( $r = .75$ ,  $p < .01$ ); similar correlations were observed in the visual meditation technique. The four test-retest subjects showed no significant changes and variability within structures of less than 5%.

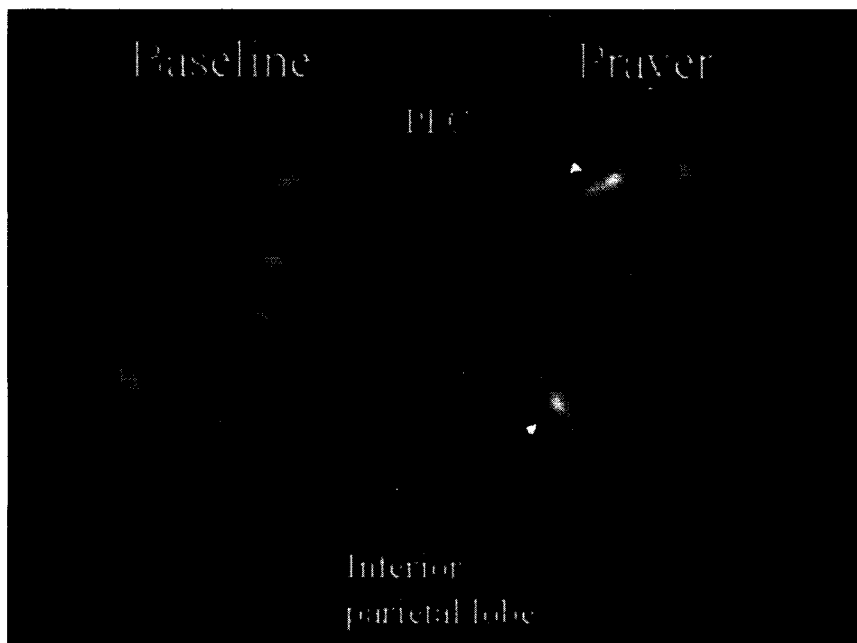


FIG. 1. The images are axial views of the brain just above the thalamus representing a baseline and prayer scan. The prefrontal cortex (PFC) is located toward the top of the scan and the inferior parietal lobe is located along the bottom of the scan (arrows). The images demonstrate increased activity in the PFC (on this gray scale image the whiter the region, the more activity) and increased activity in the inferior parietal lobe, particularly along the left.

#### DISCUSSION

In this preliminary study of meditative prayer, in spite of the limited sample size, several hypotheses could be addressed. The hypothesis that there should be increased cerebral blood flow in the frontal cortex was supported by the results and is consistent with other imaging studies of meditation (Herzog, *et al.*, 1990-1991; Lazar, *et al.*, 2000; Newberg, *et al.*, 2001). Such findings are consistent with those from other studies that have shown increased activity in the prefrontal cortex during attention focusing tasks

(Frith, Friston, Liddle, & Frackowiak, 1991; Pardo, Fox, & Raichle, 1991). The hypothesis that there would be altered cerebral blood flow in the superior parietal areas was supported by the inverse correlation between cerebral blood flow in the left prefrontal cortex and the left superior parietal lobe, similar to findings during visuospatial tasks (Cohen, Kosslyn, Breiter, DiGirolamo, Thompson, Anderson, Bookheimer, Rosen, & Belliveau, 1996; D'Esposito, Aguirre, Zarahn, Ballard, Shin, & Lease, 1998). Were such a correlation corroborated in a larger sample, this would suggest that such an interaction may also occur during meditative practices. There were no consistent changes in the midbrain, sensorimotor areas, or temporal lobe, unlike the temporal lobe changes which have been implicated in religious and spiritual experiences (d'Aquili & Newberg, 1993; Persinger, 1993; Cook & Persinger, 1997). An unanticipated finding was increased blood flow in the inferior parietal region, generally known to be associated with language. If corroborated in a larger sample, and more specifically localized, it may reflect the effects of verbal meditation.

We present these preliminary data to describe how neuroimaging techniques can be used to detect changes in cerebral blood flow during different types of meditative practices. This methodology should be applicable to a variety of practices to explore how different types of meditation are associated with different neurophysiological correlates; however, several problems must be considered. One problem is the difficulty in measuring subjective experiences and correlating these with imaging findings. Subjects filled out questionnaires after this study, but these subjective responses were impossible to quantify or analyze in a useful manner. While the subjects felt they had an adequate meditation session, researchers might attempt better methods of evaluating the actual experiences as well as correlating imaging results with other physiological parameters such as electroencephalography, hormone levels, and autonomic function. This study also measured cerebral blood flow at a single point during meditation, a lengthy process that requires time for various cognitive and affective responses to occur. Thus, images are taken only during the assumed "peak" of meditation and may, in fact, reflect cerebral blood flow during some other component of the meditation. Further studies might be designed to obtain data throughout the session. While subjects functioned as their own controls (the baseline scan) in this study, it might be argued that other states may also be associated with similar findings. Studies with larger samples may generate data with which to address such issues. These preliminary results are obviously severely limited by sample size, given the problem of finding highly proficient practitioners. However, the results are promising and also may help to inform design of studies in terms of methodological issues.

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*Accepted August 11, 2003.*