Original Papers

Cerebral Blood Flow Effects of Yoga Training: Preliminary Evaluation of 4 Cases

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Abstract

Objectives: Experienced practitioners of yoga have been shown to alter brain function, but this case series measured cerebral blood flow before and after a 12-week training program in Iyengar yoga (IY) for naïve subjects. **Methods:** On the first day, each of the 4 subjects listened to the teacher speaking on the history and background of the yoga program while they were injected with 250 MBq of ^{99m}Tc-bicisate and received a single photon emission computed tomography scan (pre-program baseline). Subjects then had their first IY training and were injected and scanned with 925 MBq bicisate while they did their first meditation (pre-program meditation). Subjects then underwent a 12-week training program in IY and then underwent the same imaging protocol with a postprogram baseline and postprogram meditation scan. Baseline and meditation scans, before and after training, were compared using paired *t* tests.

Results: There were significant decreases ($p < 0.05$) between the pre- and postprogram baseline scans in the right amygdala, dorsal medial cortex, and sensorimotor area. There was a significant difference ($p < 0.05$) in the pre- and postprogram percentage change (i.e., activation) in the right dorsal medial frontal lobe, prefrontal cortex, and right sensorimotor cortex.

Conclusions: These initial findings suggest the brain experiences a “training effect” after 12 weeks of IY training.

Introduction

Meditation and yoga practices have been increasingly evaluated in the prevention and treatment of various diseases. A number of clinical studies have reported that meditation practices can improve anxiety and depression, hypertension,² stress,³ and general well-being in various patient populations. Larger reviews of the results from studies on different types of meditation and yoga-based practices have also been reported and demonstrate the great diversity of techniques and effects.^{4–6} Several more recent articles have reported that such practices do not provide significant effects along different health measures such as anxiety or depression⁷ as well as hypertension and other clinical condi-

tions.⁴ In fact, it is likely that a much more specific nomenclature for different practices will be necessary in the future, but this is beyond the scope of this brief report.

However, the neurophysiologic mechanisms that underlie the clinical effects of these practices have yet to be studied. Several studies have specifically evaluated the neurophysiologic correlates of the acute performance of meditation and yoga practices, with most of these studies involving expert practitioners who were highly adept at these practices.^{8,9} There have been no imaging studies that have explored whether novice individuals can effect long-term changes in the brain as the result of a sustained training program.

The only neurophysiologic study to date on the long-term effects of meditation was by Davidson et al., who showed

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that there were significant changes over time in the electroencephalogram (EEG) of the brain.¹⁰ In particular, they observed that an 8-week mindfulness-based meditation program resulted in increases in left-hemispheric anterior activation. The study presented in this paper represents the first preliminary single-photon emission computed tomography (SPECT) study of the long-term cerebral blood flow (CBF) effects of a yoga/meditation training program.

It is important to note here that meditation refers to a large variety of practices that range from purely relaxation based to those performed with the goal of attaining powerful spiritual experiences. This variation, in itself, makes the study of such practices difficult. However, we have tried to find similarities among these practices, and feel that enough prior studies have demonstrated changes associated with these practices so that it seems worthwhile to continue to explore them.

The study presented here is a case series derived from a larger clinical trial of a program of Iyengar yoga (IY) in the treatment of mild hypertension. IY is a form of yoga that uses various props such as pillows and chairs to facilitate the ability of individuals to attain the necessary *asanas* (postures) involved in yoga. An important part of this type of yoga, as with many types of yoga, includes meditation and breathing exercises. Since this was a 12-week program of novice individuals with no psychiatric or neurologic disorders, we studied a small subset to determine whether there were differences in both the baseline CBF pattern as well as the activated CBF pattern during meditation.

We have previously described a number of significant changes in the brain of experienced meditation practitioners, particularly in the frontal lobes, but also in the thalamus, superior parietal lobe, and basal ganglia.¹¹ We anticipated that the yoga participants would demonstrate similar changes, but only after the 12-week training program.

We would like to emphasize that SPECT imaging and the methodology used for these subjects were chosen over other imaging techniques for several important practical reasons. Functional magnetic resonance imaging (fMRI), while having improved resolution over SPECT and the ability of immediate anatomic correlation, would be very difficult to utilize for the study of meditation because of the noise from the machine. While cerebral glucose metabolism with positron emission tomography provides better resolution than SPECT, the uptake of fluorodeoxyglucose (FDG) occurs over 30 minutes and the meditation involved in the IY program was approximately 10 minutes long and thus, we were concerned that the FDG PET results would be diluted by nonspecific uptake. Thus, while PET and fMRI offer certain technical advantages, SPECT appeared to provide the best option for these initial studies of meditation.

Since the data presented are derived from a case series of 4 subjects, we must emphasize that the results should be viewed as very preliminary, but provide a basis for exploring yoga and meditation practices in a longitudinal manner, which has not been adequately reported in the literature. This report also raises many important methodological questions that must be addressed if future studies are to provide sufficient and accurate data regarding the neurophysiologic correlates of these practices.

Methods

Subjects and imaging acquisition

Four (4) subjects with prehypertension or stage 1 hypertension, but no other significant medical or psychiatric history, were recruited to participate in this imaging study. There were 2 men and 2 women with ages ranging from 41 to 51 years with a mean age of 45 years. Each subject had no significant experience with meditation or yoga. Subjects were studied on their first yoga training day and then again after the 12-week training program. On the first day of the study, after obtaining informed consent (approved by the human subjects Institutional Review Board with the study protocol), a room was set up in the hospital to function as a yoga room. Approximately 20 minutes prior to the baseline scan, an intravenous cannula (IV) was placed in one arm so that all injections could be performed without touching or disturbing the patient. The subjects reported minimal discomfort from the IV that resolved prior to initiating the remainder of the study. The subject was instructed to rest in the room with their eyes closed and listened to the yoga teacher provide an instructional description of IY for 10 minutes. Five (5) minutes into this session, the subject was injected through the IV with 7–10 mCi of ^{99m}Tc-bicisate (Bristol-Myers Squibb Medical Imaging, N. Billerica, MA), prepared as specified by the manufacturers. Thus, they continued to listen for the next 5 minutes while the tracer uptake occurred in the brain. Approximately 15 minutes following the injection, the subject was scanned for 45 minutes in a Picker-Prism 3000XP (Picker Inc., Cleveland, OH) triple-headed rotating gamma camera using ultra-high-resolution fanbeam collimators. This scan was labeled the pre-program baseline scan.

Projection images were obtained at 3°-angle intervals on a 128 × 128 matrix (pixel size 3.56 mm × 3.56 mm) over 360° by rotating each head 120°. These SPECT images were reconstructed in the transaxial, coronal, and sagittal planes using filtered backprojection, followed by a low-pass filter and first-order Chang attenuation correction (attenuation coefficient 0.11 cm⁻¹). The reconstructed slice thickness was 4 mm with a spatial resolution of 8–10 mm.

Following this pre-program baseline scan, the subject returned to the room for their first yoga training session with the yoga instructor. Subjects worked with the instructor on various yoga postures using the props for approximately 1 hour. At the end of the postures, subjects were asked to lie down and listened to the yoga teacher guide them through a 10-minute closing meditation, which included focusing on relaxed breathing and on various body parts (the subjects had their eyes closed as in the baseline condition). Five minutes into the meditation, the subject was injected with 25 mCi of ^{99m}Tc-bicisate through the IV cannula while he/she continued to meditate for approximately another 5 minutes. The meditation session was ended and 15 minutes later the subject was scanned for 30 minutes using the same imaging parameters as for the baseline study. This scan was labeled the pre-program meditation scan.

Subjects then underwent the 12-week training program on an individual basis. This program is designed to rest the participant in supported postures and promote a relaxation response (see Table 1 for more specific timelines for the program). The program opens and closes with *Savasanas*, which

TABLE 1. APPROXIMATE TIME FRAME FOR THE IYENGAR YOGA TRAINING PROGRAM EXERCISES

<i>Yoga training program exercises</i>	<i>Time</i>
Instructor introduction & organizational issues	5 min
<i>Asanas</i>	
1. <i>Savasana</i> (corpse pose)	5 min
2. Cross bolsters	5 min
3. <i>Supta Baddha Konasana</i> (supine bound angle pose)	5 min
4. <i>Supta Swastikasana</i> (supine fortunate pose)	5 min/side
5. <i>Bharadvajasana</i> (a twisting pose)	3 × 30 sec/side
6. <i>Pavannamuktasana</i> (release of wind pose)	5 min
7. <i>Adho Mukha Virasana</i> (downward facing hero pose)	5 min
8. <i>Adho Mukha Swastikasana</i> (downward facing fortunate pose)	1 min/side
9. <i>Adho Mukha Savasana</i> (downward facing dog)	1 min
10. <i>Uttanasana</i> (standard forward bend)	1 min
11. <i>Janu Sirsasana</i> (seated forward bent with bent leg)	1 min/side
12. <i>Upavisthakonasana</i> (seated forward bend with wide legs)	3 min
13. <i>Paschimottanasana</i> (full forward bend)	1 min
14. <i>Savasana</i> (corpse pose)	5 min
15. <i>Ujjayi</i> (the conqueror)— <i>Pranayama</i>	5 min

is a classic supine resting pose aimed at achieving generalized relaxation. The sequence begins with supported supine back extensions, which facilitate opening the chest. A seated spinal twist is done following supported back extensions. A supported forward extension series follows to help relax the head, neck, and facial muscles and helps maintain a state of relaxation initially achieved with the supine poses described above. The individual is then taught *pranayama* or regulation of breath while they are in *Savasana*. Finally, subjects continue the breathing exercise while they bring their awareness to each individual body part to engage in a state of deep relaxation.

Subjects initially had two yoga sessions for the first 6 weeks followed by weekly sessions, in addition to a DVD-guided home practice for the next 6 weeks. Logs were kept by each subject to ensure that they performed the yoga appropriately. By report, the subjects each performed the yoga at home a mean of approximately 20 minutes per day. Upon completion of the training program, subjects returned to the University of Pennsylvania Nuclear Medicine department to undergo a second imaging day essentially identical to the first. They received a postprogram baseline scan, underwent the 1-hour yoga session under the instruction of the yoga teacher, and then received a postprogram meditation scan. We maintained the same order in the pre- and postprogram imaging studies so that the effect of doing the yoga would not interfere with the baseline scans.

Image analysis and statistics

The images of the pre- and postprogram baseline and meditation scans were reconstructed and resliced, using an oblique reformatting program, according to the anterior-posterior commissure line so that the final two sets were at comparable anatomical sites for the analysis. A previously validated template methodology consisting of regions of interest (ROI) corresponding to the major cortical and subcortical structures was placed over the baseline scan.¹² For the purposes of this study, we examined the CBF

as measured in only a selected number of ROIs, which was hypothesis driven. The ROIs examined included the inferior frontal, superior frontal, dorsolateral prefrontal, orbitofrontal, dorsal medial cortex, inferior temporal, superior temporal, inferior parietal, superior parietal, occipital, and sensorimotor areas, as well as the amygdala, caudate, thalamus, midbrain, cerebellum, and cingulate gyrus. Each ROI (which are small and therefore represents a “punch biopsy” of any given area) had its placement adjusted manually in order to achieve the best fit according to the atlas.

FIG. 1. This figure shows transaxial slices of the preprogram baseline state (A), the preprogram meditation state (B), the postprogram baseline state (C), and the postprogram meditation state (D). Cerebral blood flow (CBF) is represented as red > yellow > green > blue. These images show substantially greater CBF in the right prefrontal cortex (arrow) in the postprogram meditation scan compared to the activity in the baseline or the preprogram meditation scans. This suggests a training effect that enhances the activation in the prefrontal cortex after the yoga program.

The ROIs were then copied directly onto the meditation scan. This was possible because the images were already resliced into the same planes as described above. The count values for the meditation scans were obtained by determining the number of counts in each ROI on the meditation scan and subtracting the number of counts in the same ROI on the baseline scan that were decay corrected to the midpoint of the two scans. Counts per pixel in each ROI were obtained for both the baseline and meditation scans and normalized to the whole brain activity. This provides a CBF ratio for each ROI compared to the whole brain. A percentage change between the meditation and baseline scans (for both the pre- and postprogram sessions) was calculated using the equation:

$$\% \text{ Change} = \frac{(\text{Meditation} - \text{Baseline})}{(\text{Baseline})} \times 100$$

A laterality index (LI) was also calculated for each of the scans to determine the relative activity of homologous regions in the left and right hemisphere using the following equation:

$$\text{LI} = \frac{(\text{Right} - \text{Left})}{1/2 \times (\text{Right} + \text{Left})} \times 100$$

Scan results were statistically evaluated using paired *t* tests comparing the pre- and postprogram baseline scans, and also the change in activation between the baseline and meditation scans for both the pre- and postprogram condition.

Results

There were significant decreases between the mean CBF ratio (expressed as the mean CBF ratio $\pm$ standard deviation, $p < 0.05$ for all regions) in the pre- and postprogram baseline scans in the right amygdala (0.92 ± 0.06 and 0.84 ± 0.09 , respectively), right dorsal medial cortex (1.22 ± 0.06 and 1.14 ± 0.05 , respectively), and right sensorimotor area (1.16 ± 0.12 and 1.09 ± 0.11 , respectively). Thus, there were changes in the baseline CBF in these brain structures after 12 weeks of IY training.

There was a significant difference ($p < 0.05$) in the pre- and postprogram percentage change (representing the change between the meditation and baseline scans) in the following structures: right dorsal medial frontal lobe (-3.0% versus $+7.2\%$), left dorsal medial frontal lobe (-2.5% versus $+6.8\%$), right prefrontal cortex ($+3.4\%$ versus $+10.1\%$), right sensorimotor cortex ($+2.0\%$ versus $+10.3\%$), right inferior frontal lobe (0.0% versus $+9.1\%$), and right superior frontal lobe (0.0% versus $+8.6\%$). Thus, these areas were all activated more substantially after meditation training compared to before training (Fig. 1).

The LI revealed significant differences when the pre- and postprogram baseline scans were compared in the following regions: anterior cingulate (-4.4% versus -2.4% , respectively, $p = 0.01$); dorsomedial frontal cortex (-1.8% versus -7.2% , $p = 0.01$); and the superior temporal lobe (0.7% versus -2.7% , $p = 0.006$). These findings suggest that the left side of these structures had greater baseline activity relative to the right, after the training program compared to before. After the training program, the change in laterality between the baseline and meditation states was significantly greater than the change before the training program (0.1% versus -3.7%). In

other words, the left side became more active during the meditation state after training compared to before.

Discussion

The primary findings of this study suggest that during this 12-week IY training program, the participants were able to induce mild, but significant, changes in their baseline brain function, and were also able to activate their brain to a greater extent during meditation after training.

These findings are consistent with that of Davidson's study, in which the resting EEG showed changes after an 8-week meditation training program, particularly in the left hemisphere. This is consistent with our finding that changes in symmetry with relatively higher activity in the left-sided structures, particularly the anterior cingulate and the frontal lobe, after training suggest that there are further changes at baseline.

However, the results in the present study are also distinguished in that we found greater overall activations in the right hemisphere rather than the left during the actual act of meditation. This is interesting since it suggests that there are differences in both the baseline brain function and how the brain is activated after an individual goes through a training program.

Our results are also consistent with the study by Lazar et al., who used structural MRI to find that long-term meditators had thicker cerebral cortices in the right anterior insula, right middle and superior frontal sulci, and left superior temporal gyrus than in controls.¹³ Thus, the Lazar study suggested more widespread permanent changes.

The baseline changes in the amygdala and sensorimotor cortex in our study are interesting since these areas underlie emotions and the perception of sensory phenomena. Since meditation has been found in some clinical studies to improve emotional responses and depression as well as alter perceptions of sensory stimuli, that these structures appear to be affected as the result of a training program is consistent.

It is particularly interesting to note that the majority of changes associated with the active meditation state were observed in the frontal lobes which is consistent with previous studies of meditation practices.^{4,5} These studies have typically observed increased activity in the frontal lobes during meditation since this area is also involved with the focus of attention,¹⁴ a common component of meditation practice. Thus, the results suggest that the subjects were not able to substantially activate these structures when they were still naïve to the meditation practice. It should be noted that we have not observed significant changes in brain activity in a test-retest paradigm in nonmeditating controls,¹⁵ and thus the results appear to reflect more specific changes associated with the yoga program. However, after training, they were able to meditate more effectively and thus activate the brain structures that have been previously reported to be involved in meditation practices. In the yoga tradition, this might be attributable to the *dharana*, in which the individual focuses the mind on specific points of the body. This attention focusing may help explain the activation of the frontal lobe structures.

Any differences between our findings and previous imaging studies of meditation may be related to the fact that the

focus of the IY program is on yoga postures and not meditation per se, and that it represents a somewhat different approach to meditation. Our studies of different meditation practices have suggested distinct cerebral activity patterns, depending on the type of practice. Thus, the results from this study are related to the entire IY program. One might try to resolve the problem regarding which parts of the IY program are responsible for the brain changes by separating out the different components (i.e., the postures versus the meditation). This may be useful for helping to determine the “active ingredient.” However, separating the components is a challenge in studying different meditation type programs since each component may ultimately have its effect as part of the larger program. This raises important challenges to the future study of such multifaceted programs.

This study is also obviously limited by the small sample size, but these preliminary results suggest the importance of evaluating the long-term effects of meditation and yoga practices in the future, especially when trying to observe clinical changes on a psychiatric or neurologic level. Another limitation is that we maintained the same sequence of baseline followed by yoga for the SPECT scanning sessions. However, we used this method in order to ensure that the baseline would not be influenced by the yoga practice and that whatever sensorimotor changes associated with the yoga would be the same for both the pre- and post-training program scans. Furthermore, the baseline condition should also be carefully regarded since we had the instructor describe IY including its history and basis for the particular exercises and meditations. This was repeated for the postprogram training program, and while it might be argued that the subjects were already used to this description, we felt that this was appropriate since the rest of the session would also be more familiar to the subject. We could have more formally standardized the description, but each IY session is somewhat individualized, depending on what the subject is capable of actually performing. Thus, we tried to make each condition consistent within a range of variability that might be anticipated for any program involving a teacher and student. Any substantial variability would have actually made it more difficult to obtain adequate differentiation between conditions and thus the ability of this study to provide any consistent findings, we feel, suggests that the conditions were relatively stable.

It should also be emphasized that this issue of the appropriate comparison states is always difficult in these studies, since using a state that is similar but does not contain active elements is difficult for studies of yoga and meditation. For example, listening to the instructor provide a description of the IY technique could have a relaxing effect and diminish the ability to detect a difference from the active meditation.

We did not do a correction for multiple comparisons with our statistical analysis, but we felt that by limiting the analysis to those regions previously identified to be affected during meditation practices and thus, presumed to be affected as stated in our hypotheses, we could prevent being overly conservative. However, future studies with a larger number of subjects would help to clarify the significance of the findings. Finally, the effects may have been more from the *asanas*, or postures, rather than from the ending meditation itself, and future studies will be needed to image the various com-

ponents of yoga in order to determine the physiologic processes associated with each component.

Conclusions

The results from this preliminary study demonstrate that the IY training program can result in long-term changes in the brain's baseline and activated CBF. It should be emphasized that these effects may have been related to any or all of the components of the IY program including the (1) yoga postures, (2) *pranayama*, and (3) a guided relaxation with awareness, described as meditation. The changes involved with IY training in particular appear to have a greater impact in right hemispheric function, particularly in the frontal lobes. Future studies will have to expand upon the current data with a larger sample size and a more intense training program.

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Disclosure Statement

No competing financial interests exist.

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