

Electroencephalographic Activity in Patients with Claustrophobia: A Pilot Study

Abstract

Background: Exposure to small confined spaces evokes physiological responses such as increased heart rate in claustrophobic patients. However, little is known about electrocortical activity while these people are functionally exposed to such phobic situations. The aim of this study was to examine possible changes in electrocortical activity in this population. **Method:** Two highly affected patients with claustrophobia and two healthy controls participated in this *in vivo* study during which electroencephalographic (EEG) activity was continuously recorded. Relative power spectral density (rPSD) was compared between two situations of being relaxed in a well-lit open area, and sitting in a relaxed chair in a small (90 cm × 180 cm × 155 cm) chamber with a dim light. This comparison of rPSDs in five frequency bands of EEG was intended to investigate possible patterns of change in electrical activity during fear-related situation. This possible change was also compared between claustrophobic patients and healthy controls in all cortical areas. **Results:** Statistical models showed that there is a significant interaction between groups of participants and experimental situations in all frequency bands ($P < 0.01$). In other words, claustrophobic patients showed significantly different changes in electrical activity while going from rest to the test situation. Clear differences were observed in alpha and theta bands. In the theta band, while healthy controls showed an increase in rPSD, claustrophobic patients showed an opposite decrease in the power of electrical activity when entering the confined chamber. In alpha band, both groups showed an increase in rPSD, though this increase was significantly higher for claustrophobic patients. **Conclusion:** The effect of *in vivo* exposure to confined environments on EEG activity is different in claustrophobic patients than in healthy controls. Most of this contrast is observed in central and parietal areas of the cortex, and in the alpha and theta bands.

Keywords: Claustrophobia, electroencephalography, *in vivo* study, relative power spectral density

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Introduction

Claustrophobia, being one of the specific phobias, is an anxiety disorder and the third most common among phobias in terms of prevalence.^[1,2] It is exhibited as fear of being restricted or confined to one area or small enclosed spaces. Anxiety disorders negatively affect the ability to live a normal life.^[3-5] For instance, a claustrophobic person avoids small and enclosed places that can set off fear, such as elevators, magnetic resonance imaging (MRI), airplanes, subway trains, tunnels, and car washes.^[6,7] Fear of restriction and fear of suffocation are the two separate but related prominent components of claustrophobia.^[8] The severity of fear can vary, like many other anxieties, and cause variable ranges of nervousness and panic

in different people.^[7] Symptoms of this phobia can include shortness of breath, fast heartbeat, dry mouth, and distress. These people are often very frightened even if there is not any real danger in the confined area. In fact, a claustrophobic person is frightened of what might happen in the enclosed space rather than of the enclosed space itself.^[9]

In recent years, brain mapping and electroencephalography (EEG) have been used to develop a better understanding of the human brain functionality.^[10-12] EEG signals have been investigated in mental health and anxiety disorders^[13,14] such as social phobia, snake phobia, etc. Techniques such as feature extraction, analysis of specific frequency bands, power in the signals, and network analysis or connectivity have been utilized. It seems that the application of

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EEG as an examination tool in claustrophobia disorder is missing, and it is possible to explore this brain signal for developing a better understanding of this anxiety.

There are a few studies about clinical analysis of claustrophobia^[15] and about this anxiety in MRI procedures.^[6] EEG mapping is a common tool in examining different phobias. For example, such a mapping revealed that patients with social phobia have significant differences compared to normal controls suggesting hyperarousal as an important factor of anxiety. Statistical analysis of patients with social phobia demonstrated a decrease in absolute and relative delta, and theta power, an increase in absolute and relative intermediate beta power.^[16] In another study of EEG mapping in spider phobia, only relative right parietal hyperactivation was found to be related to higher pretreatment spider phobia scores.^[17] Also in specific phobias, results show that during phobic stimulation, a significant increase of EEG relative power happens in the gamma band.^[18] Although a handful of researchers have studied EEG activity in people with different phobias, such as social phobia,^[16,19] dental phobia,^[20] spider phobia,^[21] snake phobia,^[22] specific phobia,^[18] and space phobia,^[23] there is almost none performed on claustrophobic patients.

The aim of this study is to compare EEG activity changes in the standard frequency bands (delta, theta, alpha, beta, and gamma), and different regions of the cortex in rest and claustrophobic state (which will be called test state hereafter). The main challenge in studies that expose participants to real situations (*in vivo* studies) is control of the brain activity during the experiment and noise level specifically. In this study, we have utilized the multitaper method to calculate relative power spectral density (rPSD) which is relatively immune to the noise. This is due to high-frequency resolution and low variance compared to other methods. In this study, the objective was to find a pattern of change in rPSD in different frequency bands in various regions of the cortex while exposed to the phobic environment compared to being at the rest situation. To the best of our knowledge, this study should be among the first investigations of claustrophobia with EEG modality. The outcomes of such studies could be of interest to rehabilitative paradigms.

The remainder of this paper is organized as follows: Section 2 in addition to experimental materials explains EEG data acquisition and preprocessing. Section 3 provides analysis methods including relative power spectrum density extraction and statistical analysis. Section 4 presents results and discussion. Finally, conclusions are discussed in Section 5.

Methods: Experimental Design and Electroencephalography Recording

Participates

Two female university students who classified themselves as claustrophobics volunteered to participate in this

study (25 and 26 years of age). Two healthy controls of around the same age (25 and 24 years of age) were also recruited as a reference for comparisons. Subjects were chosen of the same sex to avoid gender differences that are frequently mentioned in the literature.^[20] Participants were given oral explanations of the experimental procedure involving their brain activity recording and provided informed consent letter. It was explained that during the experiment, at any stage, if they feel uncomfortable, they can ask the procedure to be stopped immediately. Participants were all nonsmokers, right handed, and with no history of neurological illnesses. They were also asked to withheld taking any medication before the experiment session. This study was approved by the research ethics committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1398.690).

Design of study

This experiment was designed to compare the change in EEG activity between two claustrophobic patients and two healthy controls. An *in vivo* design was chosen for this experiment in which all participants would enter a real-life situation that would most probably invoke phobia. This setup would be basically different from experiments in which a visual stimulation is provided to the participant during EEG recording, and each would have their advantages or shortcomings.^[24,25]

Before the recording of the EEG signal, the participants were provided with the claustrophobia questionnaire^[7] which evaluates the severity of their conditions. Furthermore, they were asked to evaluate themselves as claustrophobic or not. The first part of the experiment was performed in a well-lit large room. After putting on the cap with electrodes and preparing it, the participants were asked to sit in a relaxed position with eyes open on a chair. They were asked to remain relaxed and avoid making extra body or eye movements. During this first part, EEG signals were recorded for 5 min. Parts of this collected data would be removed due to preprocessing and a minimum of 280 s of data would be available for each participant. In the second experiment, the subjects were asked to sit on a similar chair in a confined wooden room with dimensions of 90 cm × 180 cm × 155 cm (width × length × height). There was enough light in this area and the duration of EEG recording was similarly 5 min. To inhibit artifacts, the subject's ongoing EEGs were continuously monitored by experimenters during both experiments.

Electroencephalography data acquisition and preprocessing

EEG signals were recorded according to international standard 10–20 system from 31 channels (Mitsar, 24 bit A/D, 2000 Hz/channel sampling rate). Figure 1 shows the positions of the EEG electrodes on the scalp. The EEG data were stored online at a sampling rate of 500 Hz. Also, all channels were band-stop filtered between 48 and 52 Hz

for the elimination of line power noise. While preparing the electrodes, impedances below 10 K ohms for each electrode site were considered acceptable. The electrodes in both the right and left hemispheres were referenced to the average potential of earlobes ($[A1 + A2]/2$) and with the ground at the A2 (right) earlobe.

In order to eliminate artifacts, all data were visually inspected offline and interpolated for bad channels using MNE 0.20.3 Package in python (Open-source Python package for exploring, visualizing, and analyzing human neurophysiological data). To obtain reference-free EEG recordings, data were then transformed into common average reference. Eye movement, blink, and heartbeat artifacts were removed by independent components analysis (ICA; using the Infomax algorithm, MNE 0.20.03 package, python). Before the ICA step, all EEG signals were filtered with a band-pass filter with cutoff frequencies (0.5 Hz–45 Hz) that eliminates both low-frequency artifacts and high-frequency noise caused by muscle artifacts.

Statistical Analysis

Since the purpose was to explore brain activity as a result of being exposed to the claustrophobic situation, the EEG data in the rest situation (called rest state) were used as a base of comparison to the claustrophobic situation (called test state). Preprocessed EEG data, in each channel, are first divided into three nonoverlapping segments for spectral analysis. Then, the power spectral density (PSD) calculations on each segment were performed using the multitaper technique, due to high-frequency resolution and low variance. The reason for the division of the signal into three parts is to capture the dynamic state of signals which may change during the 5-min

exposure to the rest or test state. This variation would be otherwise lost in PSD calculations. The multitaper method, first developed by Thomson in 1982,^[26] performs very well in presence of noise and provides a more robust spectral estimation than Welch's periodograms and other classical methods, and has the advantages of both methods.^[27]

After calculating the PSD spectrum in each channel and for each segment, the value of the area under the curve for delta (0.5–4 Hz), theta (4.0–8.0 Hz), alpha (8.0–13.0 Hz), beta (13.0–30.0 Hz), and gamma (30.0–45.0) frequency bands were obtained. Figure 2 shows such area for participant P1 and the first segment of the collected data in the rest state, and for the first channel (Fp1), calculated for the theta band. In order to approximate the area under this spectrum, composite Simpson's rule is commonly utilized. In this method, the area is decomposed into several parabolas whose total sum is easily calculated.

To calculate rPSD in each band, which will be called rPSD hereafter, the resulting area was normalized afterward with respect to the total area in the spectrum^[24,25] as follows:

$$\text{rPSD} = \frac{\text{Band power}}{\text{Total power}} \quad (1)$$

Finally, to assess the effect of exposure to the claustrophobic situation, we performed two statistical comparisons. First, to assess this effect on different areas of the cortex, for each frequency band of EEG, for each channel, rPSDs of segmented data were computed for two claustrophobic participants (3 segments \times 2 participants) for each state (of Rest and Test). The same calculations were repeated for the two healthy controls. Repeated measures multivariate analysis of variance model was used to estimate the effect of these variables (31 channels \times 5 bands \times 2 states) on the relative power of EEG.

Finally, to compare the two groups of participants (claustrophobics versus controls) while exposed to phobic state (rest versus test) on the whole cortex, a two-way multivariate analysis of variance model was utilized on rPSDs (5 bands \times 2 states \times 2 groups). $P < 0.01$ was considered as statistically significant.

Results and Discussion

Questionnaire data revealed self-rated overall severity of claustrophobia to be 61, and 64 (out of 104) for claustrophobic patients #1 and #2, and 42 and 27 for the two healthy controls (#1 and #2), respectively. The effect of exposure to the phobic environment on EEG signal power separated by channels (areas of the brain) is shown in Figure 3 for each of the five bands of interest only for the two claustrophobic patients. Multivariate test results revealed that band has a significant effect on rPSD level ($P < 0.01$). As can be seen, exposure to the phobic environment (claustrophobic patients) clearly decreased average rPSDs for two bands (delta and theta), increased average rPSDs for two bands (alpha and beta), and caused a decrease of rPSD in the gamma band for most areas in the cortex.

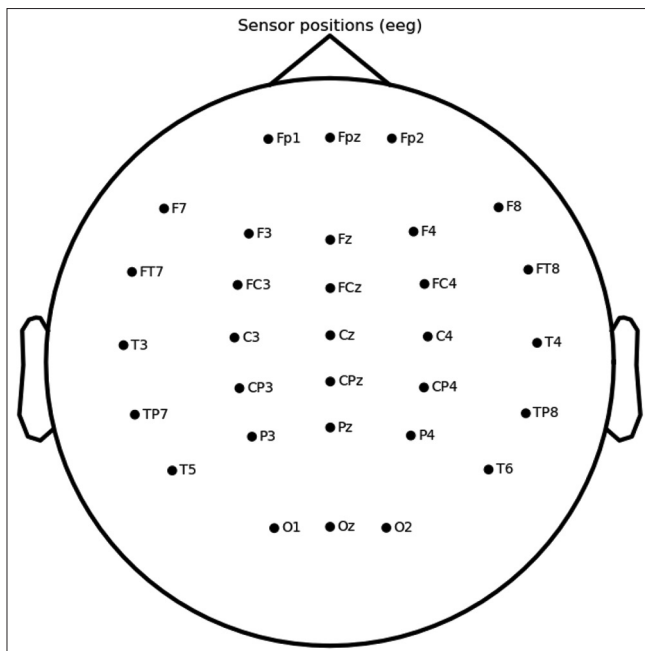


Figure 1: (Original) Electrode placement (10–20 standard). In this standard, electrodes are numbered from frontal (Fp1) to Occipital (Oz)

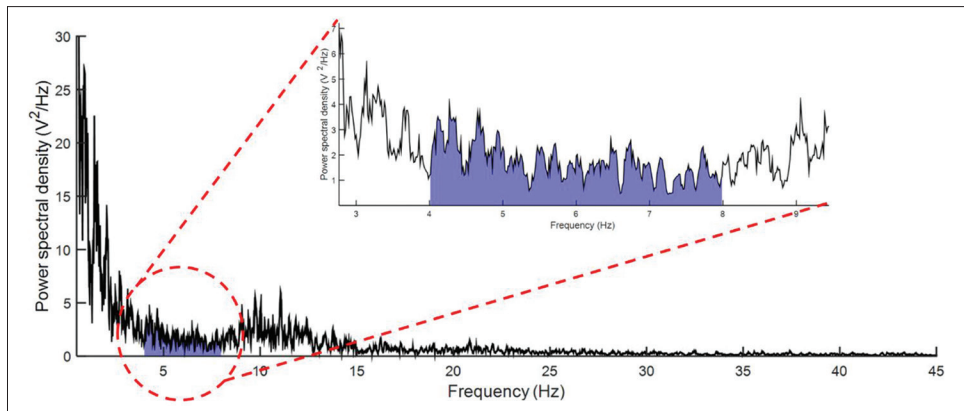


Figure 2: (Original) Area under power spectral density (estimated with the tapered method) for participant P1. Data are taken from the first segment of the rest state from channel Fp1 and highlighted for the theta band

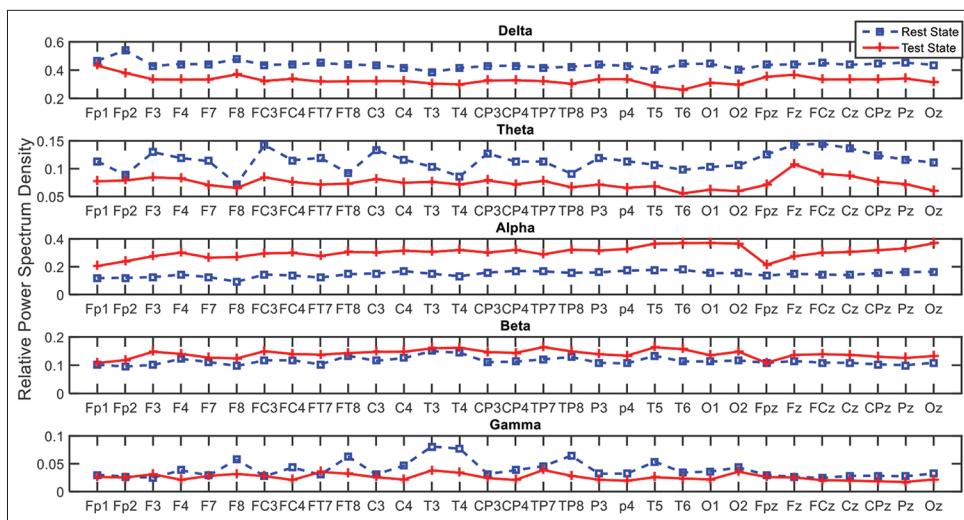


Figure 3: (Original) relative power spectral densities separated into 5 subplots for frequency bands of interest. In each band, mean relative power spectral densities (6 data points) are presented for each of 31 channels between two experimental conditions of rest/test only for claustrophobic patients

With two participants in each group, we do not have enough statistical power to examine the effect of exposure to the claustrophobic situation in different areas of the cortex. However, if we ignore the effect of multiple comparisons on α inflation, we could simplistically compare rPSDs in each band and each electrode's signal. Only for alpha band such comparisons are shown for the two groups of participants in Figure 4a and b. This could hypothetically highlight the areas of the cortex in which the effects of exposure are significant. For example, these comparisons could acknowledge that claustrophobia, like many other anxiety disorders, causes a significant change in the alpha band in parietal areas.^[21,28-31]

The aggregate effect over the whole cortex area due to exposure to the phobic state is shown in Figure 5. To display the individual differences between the subjects, the effect of phobia on the rPSDs for each of the bands is first demonstrated for the claustrophobic patients and the two healthy controls [Figure 5, the first two rows] separately. The multivariate model that evaluates the effect of exposure revealed that there was a significant interaction between exposure (rest vs. test) to the phobic

state and groups of study (claustrophobic versus control). The two-way multivariate analysis of variance showed a significant interaction between the two factors affecting the rPSDs in the electrical activity of the whole brain. The overall effect of exposure is shown in Figure 5 (rows 3–4 for each of the groups) in which patterns for each band look different between healthy controls and claustrophobic patients. Table 1 summarizes the results of interaction between situation and group while performing tests of between-subjects effect. The two bands of interest in the study of phobias were theta and alpha bands. In the theta band, being placed in the confined chamber increased electrical activity for the healthy controls, whereas it caused a clear decrease for the claustrophobic patients. In the alpha band, although this exposure to the phobic state increased electrical activity for both groups, this increase was obviously amplified for the claustrophobic patients. The most distinct change is in the alpha band (partial eta squared showed that alpha and theta accounted for 45% and 37% of the variance in the model respectively for claustrophobic patients).

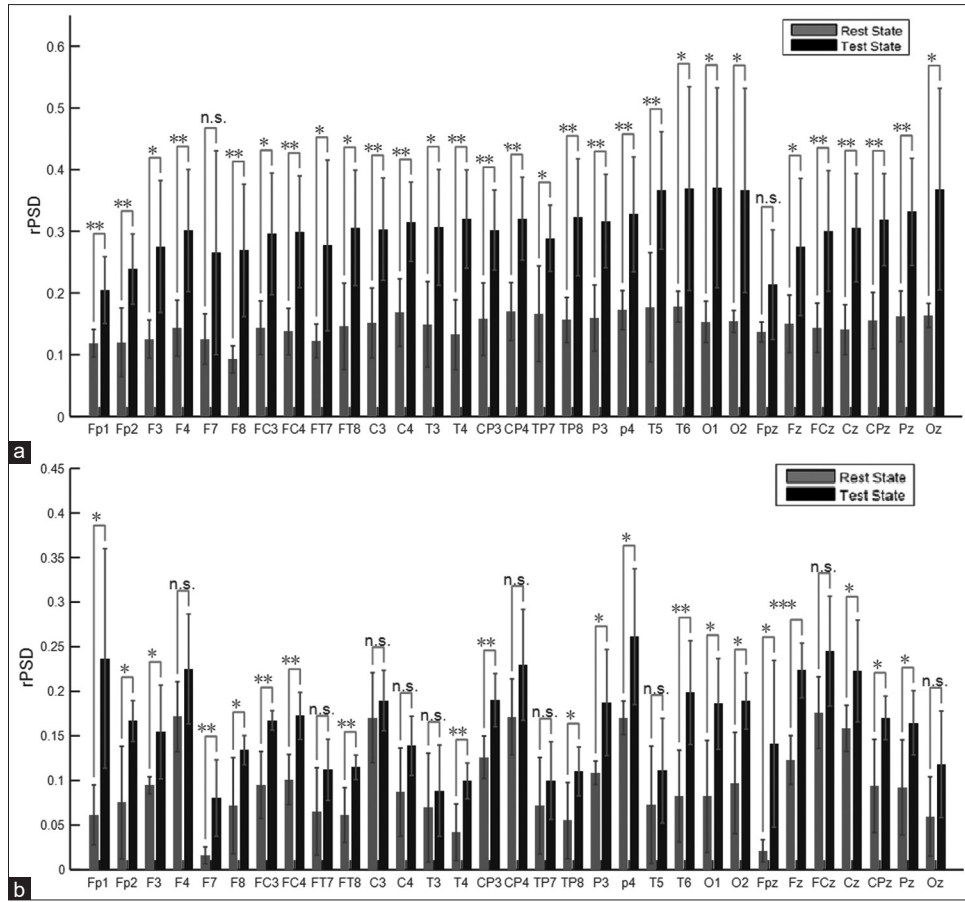


Figure 4: (Original) Average of relative power spectral density under rest and test states for alpha band, for (a) Claustrophobic Patients, and (b) Healthy Controls. (n.s. – Nonsignificant difference; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

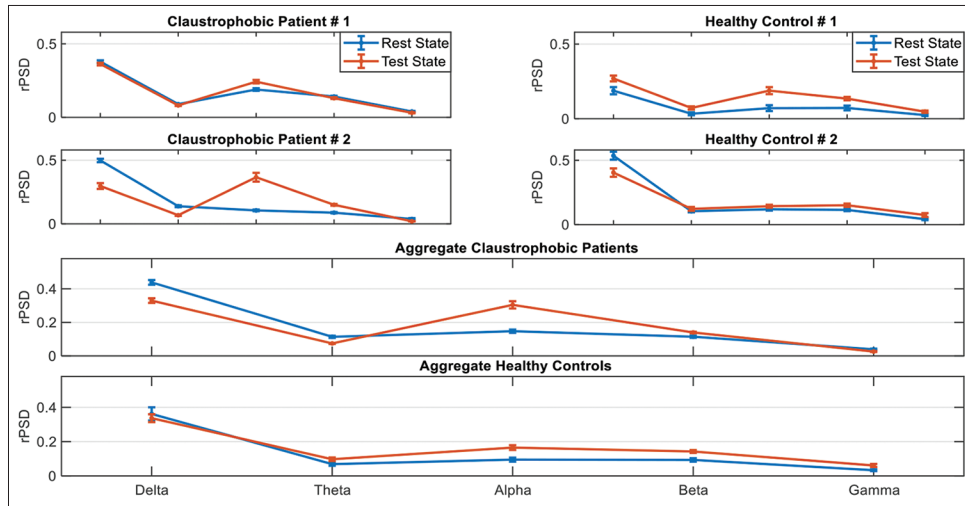


Figure 5: (Original) Comparison of average relative power spectral densities, between rest and test states separated into 5 frequency bands of interest for claustrophobic patients #1–2, and healthy controls #1–2. Aggregate values for claustrophobic patients and healthy controls are presented in 3rd and 4th rows, respectively

Conclusion

The two claustrophobic participants in this study were chosen according to the total scores of their claustrophobia questionnaire which were well above the cutoff score. Being exposed to a claustrophobic environment (compared to the

rest state) clearly altered the power of EEG in most areas of the cortex. However, the number of participants in this study did not allow us to separate the areas in which this alteration was significant. Furthermore, such exposure to phobic state created a different effect in different frequency

Table 1: Results of statistical analysis presented as the level of significance showing interaction between experimental situations (rest/test) and groups of participants (claustrophobic patients/healthy controls) on relative power spectral density in 5 different bands of electroencephalographic activity

Frequency band Group situation*	Sum of squares	df	Mean square	F	Significance
Delta	0.326	1	0.326	19.988	0.000
Theta	0.215	1	0.215	132.281	0.000
Alpha	0.349	1	0.349	57.621	0.000
Beta	0.027	1	0.027	16.975	0.000
Gamma	0.077	1	0.077	95.732	0.000

All significance values are $<.001$

bands of cortical activity. In other words, for claustrophobic patients, rPSDs increased in alpha and beta bands, whereas they decreased in delta, theta, and gamma bands.

When compared to healthy controls, the statistical analysis revealed that there is a significant interaction between the experimental situation and groups of study in all frequency bands. In other words, the way exposure to the phobic situation affects electrical activity in the brain, definitely depends on the group of study. Hence, the claustrophobic brain reacts very differently than the otherwise healthy control brain.

Finally, most of this clear change in the alpha band in claustrophobic patients comes from the change of activity in central and parietal areas of the cortex [Figure 4a] which is in accordance with the literature.^[20,21,28,29,32] To provide more reliable model of change in EEG activity in claustrophobia, there is a clear need for more comprehensive study.

Ethical standards

The study was conducted in accordance with the ethical guidelines of the Research Ethics Committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1398.690). Informed consent was obtained from both groups of participants included in the study

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None.

Conflicts of interest

There are no conflicts of interest.

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