Abstract:

Introduction: Respiratory changes are associated with anxiety disorders, particularly panic disorder (PD). The stimulation of respiration in PD patients during panic attacks is well documented in the literature, and a number of abnormalities in respiration, such as enhanced CO₂ sensitivity, have been detected in PD patients. Investigators hypothesized that there is a fundamental abnormality in the physiological mechanisms that control breathing in PD.

Methods: The authors searched for articles regarding the connection between the respiratory system and PD, more specifically papers on respiratory challenges, respiratory subtype, and current mechanistic concepts.

Conclusions: Recent evidences support the presence of subclinical changes in respiration and other functions related to body homeostasis in PD patients. The fear network, comprising the hippocampus, medial prefrontal cortex, amygdala and its brainstem projections, may be abnormally sensitive in PD patients, and respiratory stimulants like CO₂ may trigger panic attacks. Studies indicate that PD patients with dominant respiratory symptoms are particularly sensitive to respiratory tests compared to those who do not manifest dominant respiratory symptoms, representing a distinct subtype. The evidence of changes in several neurochemical systems might be the expression of the complex interaction among brain circuits.
Introduction

Respiratory changes are associated with anxiety, particularly with panic attacks (PA) and panic disorder (PD). Researchers have attempted to understand the connection between PD and respiratory system and elucidate the neurobiological circuit that underlies PAs, and hence shed light on the causes of pathological anxiety states. 

Klein proposed that spontaneous PAs occur when the brain’s perception of suffocation erroneously signals a lack of air, inappropriately triggering the alarm system derived from suffocation. Such dysfunction would make an individual vulnerable to “false suffocation alarms”, namely PAs. Respiratory tests have been fruitful in generating hypotheses about PD, indicating that CO₂ sensitivity would be part of a hypersensitive suffocation detector. PD patients exhibit both behavioral and physiological abnormal responses to respiratory challenge tests. Symptoms such as shortness of breath, “empty-head” feeling, dizziness, paresthesias and tachypnea have been described in psychiatry and respiratory physiology in relation to PD. PD patients report significantly more PAs and anxiety during respiratory challenges than normal volunteers. A number of agents have been reported as capable of provoking acute PAs in PD patients under laboratory conditions, including some respiratory challenge tests with carbon dioxide, hyperventilation, and breath-holding. These laboratory tests can induce PAs that are very similar to spontaneous PAs. The inhalation of high concentrations of CO₂ has consistently been shown to increase anxiety and induce PAs in PD patients. Among the numerous agents capable of inducing PAs in PD patients, CO₂ represents one of the most reliable panicogenic agents.

The phenomenological characterization of PAs and the response of PD patients to the respiratory tests led Briggs et al. to describe a subgroup of PD patients with prominent respiratory symptoms that presented more spontaneous PAs and responded better to antidepressants, while other patients had more situational PAs and responded better to benzodiazepines. In this line of thought, Biber et al. found that PD patients with prominent respiratory symptoms were more sensitive to the CO₂ challenge test, had a significantly longer duration of illness, more severe panic and phobic symptoms, and were more likely to be heavier smokers than patients with non-respiratory symptoms.

The objective of this review is to describe the close relationship between PD and respiration; to present the findings of the respiratory challenge tests (hyperventilation and CO₂) and their power do discriminate PD patients from normal controls and other anxiety disorder patients; to discuss, in detail, panic disorder with prominent respiratory symptoms; and also to discuss the current mechanistic concepts: increased CO₂ sensitivity, exaggerated cerebrovascular responses to hypocapnia, abnormalities of the central rhythm generator, and neurobiological abnormalities.

Diagnostic challenge tests

Hyperventilation

The acute hyperventilation challenge test may reproduce panic-like symptoms in a significant percentage of PD patients, and hyperventilation, i.e., breathing in excess to the metabolic requests, is often found in association with PAs. Respiration and its control mechanisms may play a prominent role in generating abnormal anxiety, particularly PD. Analyses locating respiratory disturbances at the core of PAs are quite recent. Since then, the amount of data supporting and deepening the understanding of a connection between the vital function of breathing and PD has persistently accumulated.

Some authors support the causal role of hyperventilation in the development of PAs: PD patients may have chronic hyperventilation that shift to hypocapnic alkalosis as a consequence of stress-induced acute hyperventilation, thus yielding PAs. This hypothesis has been built over three main experimental evidences. First, PAs and the “hyperventilation-syndrome” show common symptoms, such as dyspnea, palpitations, tremors, paresthesias, and faintness. Second, the hyperventilation syndrome has been reported to overlap with PD in about 40% of patients. Third, the acute hyperventilation challenge test, in which patients hyperventilate (30 breaths per minute) during 4 minutes, reproduces panic-like symptoms in a significant percentage of PD patients. A growing number of studies questions the ability of acute hyperventilation to induce PAs. They suggest that even though it is able to induce some anxiety, hyperventilation cannot trigger a reaction similar to spontaneous PAs in PD patients. Experimental evidence suggests that hyperventilation is a significant component of PD, but questions the idea of a putative causal role. It is, however, unquestionable that some PD patients show symptoms related to hyperventilation as also suggested by the evidence of a relationship between the severity of hyperventilation-induced anxiety symptoms

Table 1 Physiologic changes during respiratory challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>pCO₂</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperventilation</td>
<td>↓</td>
<td>• Vasoconstriction and decrease in cerebral blood flow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Panic attack.</td>
</tr>
<tr>
<td>CO₂ inhalation</td>
<td>↑</td>
<td>• Stimulation of chemoreceptors.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased ventilation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Activation of an abnormally sensitive fear network that includes the central nucleus of the amygdala, hippocampus, periaqueductal gray region, and other brainstem areas.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Panic attack.</td>
</tr>
</tbody>
</table>

pCO₂: Partial pressure of CO₂ in the blood.
and gradual decrease in cerebral blood flow in response to hypercapnia-induced alveolar hyperventilation.3,5

Stress-induced hyperventilation produces symptoms that people are prone to misinterpret as life-threatening if they are unaware of the consequences of overbreathing.11 Misinterpretation of these symptoms increases fear and activates the autonomic nervous system resulting in increasing respiratory frequency that will further washout CO2 and intensify hypocapnic symptoms.1 Hyperventilation has been considered as a cause, a correlate, and a consequence of panic attacks.22,26

Nardi et al.13 described the clinical features of hyperventilation-induced PAs in PD patients and compared them with their spontaneous PAs and with spontaneous PAs in PD patients not sensitive to the hyperventilation challenge test. Eighty-eight PD patients were submitted to a hyperventilation challenge test. A total of 51.1% (n = 45) PD patients developed a PA after hyperventilating. The clinical symptoms of the most severe PA were recorded by the patients that experienced hyperventilation-induced PAs and by the PD patients not sensitive to this test (non-hyperventilation-induced PA) in a diary during a 1-week period and then compared. The hyperventilation-induced PA group had more frequent and severe respiratory symptoms, fulfilling the criteria for the respiratory PD subtype.18

Our group has been studying the relationship between hyperventilation and PA, contrasting PD patients with normal control subjects,27 with healthy first-degree relatives of the patients,26 and other anxiety and mood disorders.25,28,29 In all instances, the PD group presented a higher sensitivity to the hyperventilation challenge test. In a previous study, we submitted PD patients to the hyperventilation challenge test and compared the patients that developed PAs with those that did not present PAs.3 Patients who panicked during the test had more frequently a family history of mental disorder, older age at the disorder onset, and more frequent previous depressive episodes. The spontaneous and induced PAs were very similar in those subjects that exhibited a PA, but in those individuals that did not develop panic after hyperventilating, the spontaneous PAs were accompanied by a larger amount of chills/hot flushes and much less frequent respiratory symptoms, such as shortness of breath, choking sensation, chest pain/discomfort, paresthesias, and fear of dying.

Although these data seem to support the idea of a causal role of hyperventilation, several pieces of evidence argue against it1,30-35 and suggest that even though it is able to induce some anxiety, hyperventilation cannot induce a reaction similar to spontaneous PAs in PD patients.36 Spontaneous PAs, as a rule, are not associated with a decrease in pCO2 levels,37-39 and several studies reported the absence of baseline chronic hyperventilation in PD patients.10,40,41 The studies that did find signs of chronic respiratory alkalosis were inconclusive, as these signs were not documented in more than 50% of the patients.42-44 If present, chronic hyperventilation seems far from being specific for PD subjects: it was so often found in patients with other anxiety disorders.35 Finally, many studies1,32,34 but not all45 show that hypercapnia is definitely a stronger panicogenic challenge than hyperventilation.

Table 2 Differences between the respiratory subtype and the non-respiratory subtype

<table>
<thead>
<tr>
<th>Evidence type</th>
<th>RS</th>
<th>NRS</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familial history of PD</td>
<td>+</td>
<td>-</td>
<td>Freire et al.,80 Nardi et al.,79 Nardi et al.77</td>
</tr>
<tr>
<td>Comorbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With agoraphobia</td>
<td>+</td>
<td>-</td>
<td>Roberson-Nay et al.75</td>
</tr>
<tr>
<td>With SAD</td>
<td>+</td>
<td>-</td>
<td>Roberson-Nay et al.75</td>
</tr>
<tr>
<td>With GAD</td>
<td>+</td>
<td>-</td>
<td>Roberson-Nay et al.75</td>
</tr>
<tr>
<td>With specific phobia</td>
<td>+</td>
<td>-</td>
<td>Roberson-Nay et al.75</td>
</tr>
<tr>
<td>Scores in PD severity scales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical Global Impression</td>
<td>+</td>
<td>-</td>
<td>Valença et al.78</td>
</tr>
<tr>
<td>Anxiety Sensitivity Index</td>
<td>+</td>
<td>-</td>
<td>Onur et al.74</td>
</tr>
<tr>
<td>Panic-Agoraphobia Spectrum Scale</td>
<td>+</td>
<td>-</td>
<td>Onur et al.74</td>
</tr>
<tr>
<td>Sensitivity to CO2 challenge tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5% rebreathing challenge</td>
<td>+</td>
<td>-</td>
<td>Abrams et al.79</td>
</tr>
<tr>
<td>35% single breath challenge</td>
<td>+</td>
<td>-</td>
<td>Biber et al.19</td>
</tr>
<tr>
<td>35% double-breath challenge</td>
<td>+</td>
<td>-</td>
<td>Freire et al.,80 Valença et al.,78 Nardi et al.82</td>
</tr>
<tr>
<td>Sensitivity to breath holding challenge tests</td>
<td>+</td>
<td>-</td>
<td>Nardi et al.,89 Nardi et al.83</td>
</tr>
<tr>
<td>Sensitivity to hyperventilation challenge tests</td>
<td>+</td>
<td>-</td>
<td>Freire et al.,81 Nardi et al.81</td>
</tr>
<tr>
<td>Sensitivity to caffeine challenge tests</td>
<td>+</td>
<td>-</td>
<td>Nardi et al.56</td>
</tr>
</tbody>
</table>

PD: panic disorder; SAD: social anxiety disorder; GAD: generalized anxiety disorder; RS: respiratory subtype; NRS: non-respiratory subtype.
Carbon dioxide

The CO₂ challenge test strongly suggests a relationship between the pathophysiology of PD and disturbances in the control of breathing. Schrous et al. observed that scanty accurate information is available on the symptomatology of real-life panic attacks and how well they are reproduced by an experimental model such as the 35% CO₂ test. Possibly, research on the association between CO₂ and PD will better characterize subtypes of PD and their underlying mechanisms.

Gorman et al. observed that subjects with PD, in contrast with healthy controls, develop a panic-like reaction within minutes after starting breathing a mixture containing 5% CO₂. CO₂-induced PA is associated with cardiorespiratory activation, including increased respiratory rate and blunted tidal volume response, tachycardia, and increased blood pressure. Sanderson et al. concluded that, despite remarkable methodological differences across various studies, it has been unequivocally established that subjects with PD are hypersensitive to hypercapnic gas mixtures.

A different method of doing CO₂ challenges has also been developed, consisting of one single vital capacity breath of a gas mixture containing 35% CO₂ and 65% oxygen. When given to healthy subjects, this type of challenge results in a brief but strong respiratory stimulation accompanied by neurovegetative symptoms that largely overlap with those reported by panic patients. In PD patients the same intervention induces a sharp and transitory rise in anxiety that has been equaled with a real life PA. Administered in a controlled laboratory environment, the single breath 35% CO₂ challenge constitutes a brief test whose effects are completely vanished in a matter of seconds. Repeated studies have demonstrated that the procedure is safe and devoid of unwanted consequences both in short- and long-term. It has been established that CO₂-triggered anxiety is not merely a startle reaction generated by a strong physiological stimulus in overaroused individuals. When administered to a mixed group of patients with various anxiety disorders, all of them with comparable ratings of arousal and anticipatory anxiety, the CO₂ test affected only those with a diagnosis of PD. Specifically, patients with obsessive-compulsive disorder (OCD) failed to show any significant anxiety response to the inhalation of 35% CO₂. Similarly, patients with a generalized anxiety disorder (GAD) had little increase in subjective anxiety after a deep breath of CO₂. Among patients with a specific phobia, making a clear-cut distinction between animal and situational phobics, the 35% CO₂ challenge did not affect animal phobics, whereas situational phobics presented a CO₂-induced reaction tending to resemble that of PD subjects.

Perna et al. studied dyspnea symptoms during 35% CO₂ inhalations. About a half of the panic disorder patients reported: “I cannot take a deep breath” and “My breath does not go in all the way”. The statements: “I feel out of breath”, “My breathing requires more concentration” and “My breathing requires effort” were also very common, and more than 35% of the patients reported these symptoms. The symptoms reported were not influenced by gender, age or educational level. The authors performed a factor analysis and identified three factors which accounted for 80% of the variance: “breathing effort”, “sense of suffocation” and “rapid breath”. The factor “breathing effort” describes the conscious awareness of muscular effort during activation of respiratory skeletal muscles that is thought to arise from dissociation between a central respiratory motor command and a mechanical response of the respiratory muscles. A thoracic breathing pattern and a higher irregularity and instability in baseline breathing patterns which are characteristic of patients with PD, could affect the ability of patients with PD to maintain an adequate respiratory homeostasis when external or internal changes occur. Dissociation between the increased central respiratory command stimulated by CO₂ and a decreased mechanical efficiency of the respiratory response might, therefore, lead to a heightened sense of breathing effort during the CO₂ challenge test. The factor “sense of suffocation” arises mainly from the stimulation of chemoreceptors and involves the activation of the limbic/paralimbic and cerebellar regions. The “rapid breath” factor, which describes a shallow, rapid breathing pattern in response to an excessive mechanical load, was not associated with CO₂ reactivity.

Panicogenicity to CO₂ inhalation increases in the face of serotonin antagonists such as metergoline and tryptophan depletion. Decreases with SSRIs. These data, together with studies demonstrating blockade of CO₂-panic by benzodiazepines and tricyclic antidepressants, suggest that serotonin, GABA, and noradrenergic neurotransmission play a relevant role in CO₂-induced panic.

The influence of genetics on CO₂-induced panic has also been considered. It was suggested that CO₂ sensitivity reflects a trait marker that runs in families. According to these researchers, CO₂ sensitivity may be considered a phenotypic expression of an underlying genetic vulnerability that may exist before the clinical onset of PD. The genetic mechanisms proposed include differential expressions of chemoreceptors and neurotransmitter system activation. The ultimate isolation of genetic markers could lead to preventative measures for vulnerable individuals.

CO₂ may represent another safe and effective panicogenic method that has been considered to work primarily by stimulation of hyperventilation. It remains to be understood whether sensitivity to CO₂ and the associated hyperventilation are a characteristic of all normal subjects and PD patients undergoing PAs. It is possible that CO₂ sensitivity relates to a specific subtype of PD, a hypersensitive homeostatic response (“suffocation alarm”), or simply an indirect cause of panic by means of a nonspecific irritation of any chemical and/or mechanical receptors.

The Panic Disorder Respiratory Subtype

There is scientific evidence that a group of “respiratory symptoms” belongs to a distinct PD subtype. Briggs et al. studied the descriptions of the most recent severe PA of 1,108 PD patients and performed an analysis of the main components of the symptoms. The symptoms: fear of dying, chest pain/discomfort, shortness of breath, paresthesias, and sensation of choking defined a distinct group and the absence of these symptoms defined another group. Patients with four or five of these respiratory symptoms during a PA were assigned to the respiratory subtype group, and patients with three or fewer of these symptoms were assigned to the non-respiratory subtype group. The group with prominent
respiratory symptoms suffered more spontaneous PAs, whereas patients in the non-respiratory subtype group had more situational PAs.

Recent studies indicate that respiratory subtype patients may have higher rates of familial history of PD, lower neuroticism scores, and higher scores in severity scales compared to non-respiratory subtype patients. Roberson-Nay et al. studied the PD respiratory subtype in an epidemiologic sample (n = 2,294) and in a clinical sample (n = 1,169) and found high temporal stability for the subtype. The authors also found higher comorbidity rates with agoraphobia, social anxiety disorder, generalized anxiety disorder and specific phobia for the respiratory subtype, compared to the non-respiratory subtype. In two studies with small samples, it was found correlation between the respiratory subtype and low comorbidity with major depressive disorder, but in the study from Roberson-Nay et al. they found the opposite. There are also conflicting findings regarding the duration of illness. High prevalence of respiratory symptoms was found in patients with nocturnal PAs or traumatic suffocation history.

Biber et al. examined the sensitivity to CO₂ in PD patients based on the subtypes approach. PD patients with prominent respiratory symptoms were more sensitive to the CO₂ challenge, had a significantly longer duration of illness, more severe panic and phobic symptoms, and were more likely to be heavier smokers than were PD patients with non-respiratory symptoms. Valença et al. also aimed to assess the sensitivity to CO₂ challenge test in twenty-seven PD subjects classified into respiratory and non-respiratory subtypes. Fifteen of 16 (93.7%) respiratory PD subtype patients and 5 of 11 (43.4%) non-respiratory PD patients had at least one PA during one of two CO₂ challenges. Respiratory subtype patients were also more sensitive to the 5% CO₂ rebreathing challenge than the non-respiratory subtype patients. Using the 35% CO₂ challenge test and the hyperventilation test, Freire et al. compared 117 patients with the respiratory and non-respiratory subtypes of TP. The respiratory group was more responsive to the tests: 80.3% panicked with CO₂ and 53.0% with the hyperventilation test. Only 11.8% of the non-respiratory patients had PA during the carbon dioxide test and 33.3% during the hyperventilation test. These studies indicate that the respiratory subtype group is more sensitive to the CO₂ challenge test and less sensitive to the hyperventilation test, when compared to the non-respiratory subtype group. Other studies also found that most of the PD patients who had PAs during the hyperventilation, the breath-holding and the caffeine tests met the criteria for the respiratory subtype.

There is evidence that the respiratory and non-respiratory subtypes respond differently to drugs. In an 8-week medication trial, the respiratory subtype patients presented a better improvement with imipramine, while non-respiratory subtype patients responded better to alprazolam. In another study, the respiratory subtype patients had a faster response to treatment with nortriptyline at 8 weeks, compared to the non-respiratory subjects; however, at 52 weeks both groups had improved equally. Clonazepam yielded a similar behavior in the respiratory PD, i.e., a faster improvement of the symptoms in the beginning of the treatment and a response similar to that of the non-respiratory subtype on the long run. Mavissakalian found that respiratory symptoms, particularly choking, dyspnea and fear, improved significantly at four weeks of treatment with imipramine, whereas other symptoms took longer to improve. Respiratory and non-respiratory subtype patients improved in a similar way with cognitive-behavioral therapy.

Current Mechanistic Concepts

Increased CO₂ sensitivity

There are two lines of evidence suggesting that PAs may originate in the brainstem. The first one advances that the nature of the symptoms can be explained by a surge of impulses from the autonomic nervous system. The second line of evidence is the CO₂-mediated experimental provocation of PA itself. CO₂ primarily acts on the brainstem, especially on the respiratory center, located in the reticular substance of the medulla oblongata and the pons. Considering the hyperoxic mixtures that are used in the CO₂ challenges, any stimulating influence of the peripheral oxygen chemosensitive areas is discarded. A number of studies were directed towards a possible dysfunction at the level of the central chemosensitive regions.

To explore CO₂ chemosensitivity in PD patients, the ventilatory response to increasing CO₂ concentration was monitored under the hypothesis that an exaggerated response would confirm oversensitivity. Studies on the ventilatory response to CO₂, i.e., the increase in ventilation due to the inhalation of increasing concentrations of CO₂, yielded contradictory results (Gorman et al.). This may be in part explained by a possible lack of control of confounding variables and the well-known wide inter-individual variability of CO₂ chemosensitivity. Klein proposed that PA results from the deregulation of a phylogenetically evolved alarm system directed to monitor suffocation signals in the organism. This alarm system has been evolutionarily programmed to fire when it senses metabolic signals of asphyxia and impending death. As a survival alert system, this physiologic suffocation monitor most likely has a deeply rooted adaptive function: its activation only occurs in extreme life threatening circumstances. The Klein’s hypothesis may help to understand the preeminence of respiratory symptoms in PAs. For example, it may be useful to explain why patients with PD, in contrast with other types of anxiety, against any medical evidence, and despite repeated reassurance, invariably feel an overwhelming fear of dying and losing control during their attacks. Klein points to the existence of the congenital central hypoventilation syndrome. This rare condition affects infants that apparently are born with an aberrant sensitivity to signals of hypercapnia and hypoxia. The congenital hypoventilation syndrome may be the pathophysiological mirror picture of PD.

A drawback of Klein’s hypothesis rests on the fact that no suffocation alarm system has been anatomically or functionally identified as such within the central nervous system (CNS). The search for a panic circuitry in the brain should include those areas of the CNS linked to chemosensitive properties. These structures should logically be considered as the best candidates to fulfill the function of a suffocation detector. A few findings support the idea that the CNS chemosensitive areas related to panic responses extend to several
and tidal volume were found to be more irregular than
sleep.87,94 In PD patients, baseline respiratory frequency
minute ventilation and an increased rate of apneas during
patients with PD, healthy controls, or patients with other
results of a mismatch of the activity of inspiratory and
spiratory sensations that ensue in patients with PD, could be
PD. Normal respiration is characterized by a synchronized
action of inspiratory and expiratory neurons and, thus, the
high variability observed, together with the unpleasant re-
spiratory sensations that ensue in patients with PD, could be
the results of a mismatch of the activity of inspiratory and
expiratory neurons. The abnormal responses to respiratory
challenges might be the expression of a deranged adaptation
mechanism related to this deregulation.6,22

Changes of the central rhythm generator
Breathing pattern at rest may reveal some changes in venti-
latory control. Accordingly, several studies investigated PD
subjects focusing on baseline respiratory physiology in the
intervals between Pas.31,37,58 However, caution is needed when
interpreting these results, as several measurements were
obtained immediately before panicogenic challenges, and
procedures used to obtain these data are heterogeneous.
Most of the studies performed so far failed to find significant
differences in mean values of respiratory rate, tidal vol-
minute ventilation and respiratory blood gases among
patients with PD, healthy controls, or patients with other
anxiety disorders.22 The two main positive findings that have
been reproduced are: 1) patients with PD have a thoracic pat-
tern of breathing28 with a strong muscular thoracic effort; 2)
patients with PD show an abnormal variability and irregularity
in breathing both during daytime11,48,90,91 and during sleep.87

Other interesting findings are the hematologic altera-
tions found in patients with chronic obstructive pulmonary
disease and high altitude dwellers which were also found
in PD patients.92 Ross et al.92 found that male PD patients,
particularly those sensitive to CO2 inhalations, had elevated
mean corpuscular hemoglobin. This finding indicates that
compensatory mechanisms to hypoxia may be activated in
PD patients.

Because respiration is a complex physiologic function with
multiple central and peripheral inputs, its pathophysiologic
characteristics could be more accurately investigated by
the analysis of the complexity of the respiratory recorded signals
rather than by a simple measurement of the absolute values
of a few parameters. Patients with PD show a larger breath-
to-breath variability during a rebreathing test than is usually
observed in controls.93 Compared with healthy subjects, PD
patients show an increased irregularity in tidal volume and
minute ventilation and an increased rate of apneas during
sleep.87,94 In PD patients, baseline respiratory frequency
and tidal volume were found to be more irregular than
in healthy controls.11,48,90 Additionally, PD patients showed
excessive sighing and tidal volume irregularity significantly
greater than those in healthy control subjects95,96 and GAD
patients.97 The tidal volume irregularity persisted after both
doxapram-induced hyperventilation and cognitive interven-
tion, suggesting that it might be an intrinsic and stable
feature of patients with PD.97 The importance of this finding
for the understanding of panic etiopathogenesis is supported
by the evidence of a higher variability in respiratory pattern
in response to 5% CO2 inhalation in relatives of PD patients
compared to relatives of healthy controls and of affective
patients.38 In connection, Perna et al.99 suggested that
the variability in respiration might be higher in children of
patients with PD than in those born to healthy controls. Two
trials108,109 reported more irregularities in respiratory rate in
children with childhood anxiety disorders that developed
panic symptoms after CO2 inhalation. Respiratory irregu-
larities and pattern variability could be a physiological trait
marker of panic vulnerability able to identify subjects at risk
for PD and promote formal and molecular genetic studies in
PD. Normal respiration is characterized by a synchronized
action of inspiratory and expiratory neurons and, thus, the
high variability observed, together with the unpleasant re-
spiratory sensations that ensue in patients with PD, could be
the results of a mismatch of the activity of inspiratory and
expiratory neurons. The abnormal responses to respiratory
challenges might be the expression of a deranged adaptation
mechanism related to this deregulation.6,22

Dysfunctional opioid system
The opioid system participates in breathing regulation and
social-affiliative behavior explaining the associations be-
tween separation anxiety disorder (SAD), CO2 and lactate
sensitivity, other respiratory phenomena, and PD.102 In
the extended version of the false suffocation alarm theory, an
episodic dysfunction in the endogenous opioid system regu-
lation explains the false alarms in PD patients.102 SAD patients
have high incidence of PD102 and familial history of PD.104
Roberson-Nay et al.105 found that subjects with both SAD and
at least one parent with PD were more sensitive to CO2. The
risk of a PA in these patients during a 5% CO2 inhalation was
threefold higher compared to subjects without SAD or familial
history of PD. This finding indicates that SAD combined with
familial history of PD may increase the risk of PD.105

The endogenous opioid system was recognized as an im-
portant central regulator of respiratory drive106 and, when
the opioid receptors are stimulated, CO2 sensitivity reduces
and respiratory rate slows down.107 Also, the administration
of codeine allows high levels of carbon dioxide to be toler-
ated during breath holding.108 Conversely, naloxone, an opioid
receptor antagonist, increases the ventilatory response to
hypercapnic hypoxia in normal human subjects.109 Recent
studies110-112 indicate that naloxone increases the respiratory
response to lactate in healthy subjects. In the study by Preter
et al.111 sodium lactate was administered intravenously to 25
healthy subjects who received a pretreatment with naloxone
or saline. The administration of naloxone or saline was ran-
domized and crossed-over, in two different days. Compared
to the saline group, the naloxone group had higher tidal
volume, respiratory rate and minute ventilation, but there
were no differences regarding panic symptoms and subjective
breathlessness. Among subjects pretreated with naloxone,
those with childhood parental loss (parental death or divorce
before the age of 10) showed milder increase in ventilatory parameters, compared to those without childhood parental loss. These findings indicate that the susceptibility of panic disorder patients to lactate-induced panic may imply a deregulation of the opioid system.110,111

**Neurobiological changes**

A recent model of PD attempts to integrate neurochemical, imaging, and treatment findings, coupled with mostly preclinical work, in the neurobiology of conditioned fear responses.111 The PA is speculated to originate in an abnormally sensitive fear network, centered in the central nucleus of the amygdala (CNA). The sensory input for the conditioned fear stimulus runs through the anterior thalamus to the lateral nucleus of the amygdala, then to the central nucleus of the amygdala, where all the information is gathered and the autonomic and behavioral responses are coordinated. The CNA sends stimuli to the parabrachial nucleus, increasing respiration rate;114 the lateral nucleus of the hypothalimum, activating the sympathetic nervous system; the locus ceruleus, increasing the norepinephrine release and contributing to increases in blood pressure, heart rate and the behavioral fear response; and the paraventricular nucleus of the hypothalamus, causing an increase in the release of adrenocorticooids. A projection from the CNA to the periaqueductal grey region is responsible for additional behavioral responses, including defensive behaviors and postural freezing. There are also important reciprocal connections between the amygdala and sensory thalamus, prefrontal cortex, insula and primary somatosensory cortex. Although the amygdala receives direct sensory input from brainstem structures and the sensory thalamus, enabling a rapid response to potentially threatening stimuli, it also receives afferents from cortical regions involved in processing and evaluation of sensory information. A neurocognitive deficit could result in a misinterpretation of sensory information, leading to an inappropriate activation of the “fear network” via misguided excitatory input to the amygdala. A deficiency in the coordination of the stimuli from the cortex and brainstem could lead to an abnormal activation of the amygdala, with a behavioral, autonomic and neuroendocrine activation. Panic originates in an abnormally sensitive fear network, which includes the prefrontal cortex, insula, thalamus, amygdala and amygdalar projections to the brainstem and hypothalamus.3,113

The potential role of hypoxia as a signal of asphyxia and the suggested sensitivity of PD patients to anoxia are supported by evidences from animal studies reporting that the amygdala and the hippocampus are particularly sensitive to anoxic stimulation. Together with the evidence of strong connections between the amygdala and the carotid body, the direct sensitivity of amygdala to acid-base changes, and the interconnections between the amygdala and the parabrachial nucleus114 may delineate another pathway linking respiratory signals to panic.115

**Conclusion**

There is a substantial body of literature demonstrating that stimulation of respiration is a common event in PD patients during a PA. A number of changes in respiration, such as enhanced CO₂ sensitivity, have been detected in PD patients. As a result, some investigators advanced that there is a fundamental abnormality in the physiological mechanisms that control breathing in PD. Accumulated evidence suggests that the respiratory physiology remains normal in PD patients and that their tendency to hyperventilate and react with panic to respiratory stimulants like CO₂ represents the triggering of a hypersensitive fear network. However, some recent evidences support the presence of subclinical abnormalities in respiration and other functions related to body homeostasis. Hence, the role of a more primitive and lower brain center than the limbic one should be considered. To date, the fear network has been investigated in preclinical studies that have identified the brain pathways that promote the acquisition and maintenance of conditioned fear. The amygdala and its brain stem projections, the hippocampus, and the medial prefrontal cortex operate in this network. Although attempts to image this system in patients during panic attacks have been so far inconclusive, the theory that the fear network is operative and hyperactive in PD patients might explain why both medication and psychosocial therapies are clearly effective. Although to date it is not clear if the abnormal function underlying PAs lies in the limbic system, mainly related to fear, or in the brainstem, mainly related to a primitive emotion, one cannot forget the complex relationships between these two brain areas. Therefore, the whole picture of PD should be viewed as the complex result of multiple interactions between various brain networks. The evidence of abnormalities in several neurochemical systems might be just the expression of the complex interaction among brain circuits. Hence, the attempt to focus on one isolated component of this complex array as the “pathogenetic” system of PD seems unwarranted.

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**Disclosures**

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