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Visible abdominal distension in functional gut disorders: Objective evaluation

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Abstract

Background: Visible abdominal distension has been attributed to: (A) distorted perception, (B) intestinal gas accumulation, or (C) abdominophrenic dyssynergia (diaphragmatic push and anterior wall relaxation).

Methods: A pool of consecutive patients with functional gut disorders and visible abdominal distension included in previous studies ($n = 139$) was analyzed. Patients (61 functional bloating, 74 constipation-predominant irritable bowel syndrome and 4 with alternating bowel habit) were evaluated twice, under basal conditions and during a self-reported episode of visible abdominal distension; static abdominal CT images were taken in 104 patients, and dynamic EMG recordings of the abdominal walls in 76, with diaphragmatic activity valid for analysis in 35.

Key Results: (A) Objective evidence of abdominal distension was obtained by tape measure (increase in girth in 138 of 139 patients), by CT imaging (increased abdominal perimeter in 96 of 104 patients) and by abdominal EMG (reduced activity, i.e., relaxation, in 73 of 76 patients). (B) Intestinal gas volume was within $\pm$300 ml from the basal value in 99 patients, and above in 5 patients, who nevertheless exhibited a diaphragmatic descent. (C) Diaphragmatic contraction was detected in 34 of 35 patients by EMG (increased activity) and in 82 of 103 patients by CT (diaphragmatic descent).

Conclusions and Inferences: In most patients complaining of episodes of visible abdominal distention: (A) the subjective claim is substantiated by objective evidence; (B) an increase in intestinal gas does not justify visible abdominal distention; (C) abdominophrenic dyssynergia is consistently evidenced by dynamic EMG recording, but static CT imaging has less sensitivity.

KEYWORDS

abdominal distension, abdominophrenic dyssynergia, abdominothoracic electromyography, abdominothoracic imaging, intestinal gas

1 | INTRODUCTION

Abdominal distension is an important issue in clinical practice, because it affects a large proportion of patients with functional gut disorders and constitutes their most bothersome complaint.[1–3] Frequently, patients complain of self-limited episodes of visible abdominal distension (swollen abdomen with increase in girth) that appear as the day goes on and resolve after overnight rest. In between episodes, patients report their abdomen going back to normal (no visible distension) or some residual degree of mild distension.

Visible abdominal distension is frequently, but not necessarily, associated with sensation of increased abdominal pressure/tension (abdominal bloating), but not all sensation of bloating is accompanied by visible distension. The terms distension and bloating are sometimes used indistinctively, but if properly questioned, the patients clearly identify whether they are referring to visible distension, which is the object of the present study, or to sensation of increased abdominal pressure, and this distinction is key to understanding and management of their complaint. Epidemiological studies distinguishing visible distention and bloating are scarce. A large study in the general population reported that that about half of the subjects complaining of bloating also experienced visible distension.[4] Another study found that among 542 IBS patients reporting bloating, 410 also reported distension.[5]

Visible abdominal distension in patients with functional gut disorders has been attributed, without conclusive evidence, to multiple causes, for example, bacterial overgrowth, visceral hypersensitivity, dysbacteriosis, carbohydrate intolerance, abnormal motility. However, regardless of the underlying causes, the claim of self-limited episodes of visible abdominal distension may originate by three basic mechanisms: distorted interpretation (patients believe their abdomen is visibly distended without objective evidence), transient increases of abdominal content (intestinal gas being the most likely candidate), or abnormal postural tone of the abdominal walls and redistribution of contents.[6] The latter mechanism, termed abdominophrenic dyssynergia,[7] was described by a series of studies, that measured the activity of the abdominal walls by means of abdominal CT imaging and/or abdominothoracic EMG recording and showed that episodes of abdominal distension were associated with a diaphragmatic push (increased tone and descent of the diaphragm), coupled with reduced tone and protrusion of the anterior abdominal wall.[8–10]

The aim of the present study was to determine the mechanism of visible abdominal distension in patients with functional gut disorders. Data of consecutive patients complaining of self-limited episodes of visible abdominal distension, included in previous studies,[8–10] were analyzed, to identify the percentage of patients, whose complaint is related to either distorted interpretation, increase in intestinal gas or abdominophrenic dyssynergia. Patients had been evaluated, following a standard procedure in the acquisition of CT abdominal imaging and abdominothoracic EMG recording, both during basal conditions and during episodes of severe distension, and the mechanism of distension was investigated by comparing abdominal morphovolumetric parameters between both condition.[8–10]

Practitioner's points

In patients with functional gut disorders complaining of visible abdominal distension,

1. The subjective claim is substantiated by objective evidence, and hence, patients deserve credibility and warrant medical attention.
2. The possibility of excess gas, a common belief, is very unlikely.
3. Abdominophrenic dyssynergia (diaphragmatic contraction and anterior abdominal wall relaxation) seems to be the rule in the majority of patients, although CT imaging has diagnostic limitations, particularly in the evaluation of the diaphragm.

2 | MATERIAL AND METHODS

2.1 | General procedure, participants, and experimental design

Patients whose predominant complaints were episodes of severe visible abdominal distension in the absence of organic cause were studied, that is, patients complained of episodes of severe visible abdominal distension (swollen abdomen with increased girth), and in between these episodes (basal conditions) they felt well (without or with only mild visible abdominal distension). Patients complaining of continuous, unremitting visible abdominal distension were not included in the study. Patients were instructed to come to the laboratory under two different conditions: during basal conditions, when they felt their abdomen was normal or with minimal visible distension, and during episodes of severe visible distension. On each occasion, the following outcomes were measured: patient's rating of visible abdominal distension (how severe is your visible abdominal distension now), girth measurement, abdominal or abdominothoracic CT scanning (Figure 1), and EMG recording of the anterior abdominal muscles, intercostals and diaphragm (see "Demographics and study flow" below). This paper provides a global analysis of the data of various studies with the same inclusion criteria, experimental design, and procedures.[8–10] The individual study protocols were previously approved by the Institutional Review Board of the University Hospital Vall d'Hebron (Comitè d'Ètica d'Investigació Clinica, protocol number PR[AG]60/2009 approved May 5, 2009). Written informed consent was obtained from each patient included in the study. Some of the studies were registered with ClincialTrials.gov no: NCT01205100. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee.

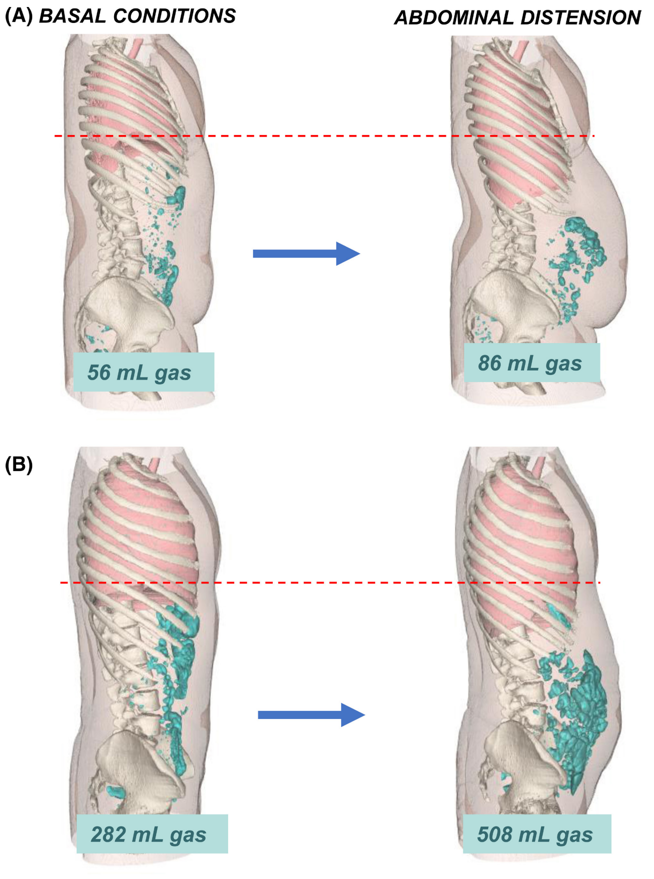

FIGURE 1 Examples of repeat CT scans (basal conditions and episodes of abdominal distension) in 2 patients (*A* and *B*). Note marked diaphragmatic descent and pulmonary insufflation regardless of intestinal gas content

2.2 | Outcome measures

2.2.1 | Patient's rating of visible abdominal distension

Patients were instructed to score the severity of their visible abdominal distension (how severe is your visible abdominal distension now) on a graphic rating scale graded from 0 (no distention) to 6 (extremely severe distention). Measurements were taken immediately before each test (CT scan or EMG). See reproducibility data in Supplemental material.

2.2.2 | Girth measurement by tape measure

Measurements were taken using adaptable belts and the trunk erect (Figure S1). Patients were sitting on an ergonomic chair and the back of the chair was adjusted to the lumbar area to fix the curvature of the spine.[11,12] A non-stretch belt (48-mm wide) with a metric tape measure fixed over it was placed over the umbilicus. The overlapping ends of the belt were adjusted carefully by elastic bands to maintain constant adaptation of the belt to the abdominal wall. Girth measurements were taken with the subjects breathing quietly as the average of inspiratory and expiratory determinations over three consecutive respiratory cycles without manipulation of the belt-tape assembly by the investigator. In the first measurement (basal conditions or distension episode), the location of the belt was marked on the skin for subsequent measurements. This method has been previously described detail and has been shown to detect reproducible, stimulus-related changes in girth in response to variations in intraabdominal content (intestinal gas infusion and meal ingestion).[13–17] In the present study, both measurements in each patient (basal and distension) were taken by the same investigator, to prevent interobserver variability bias. See reproducibility data in Supplemental material.

2.2.3 | CT scanning

Abdominal or abdominothoracic CT scans were obtained with a helical multi-slice CT scanner. Images were obtained in the supine position during a single breath hold. No oral or intravenous contrast medium was administered. Morpho-volumetric analysis of CT images was performed using an original software program specifically developed in our laboratory and previously described.[8,18] The following parameters were measured: abdominal gas content, total abdominal volume, abdominal perimeter, position of the diaphragm in reference to the cranial end-plate of the twelfth vertebra (in all scans), pulmonary air volume and thoracic anteroposterior diameter at T4 (in abdominothoracic scans). See "Supplemental material" for details.

2.2.4 | Electromyography of the abdominothoracic walls

Using electromyography (Electromyographic System ASE 16, PRIMA Biomedical & Sport, Mareno di Piave, Italy), the activity of the anterior wall and intercostal muscles was recorded via surface electrodes, and the activity of the diaphragm via intraesophageal electrodes mounted over a probe.[19] EMG recordings were conducted in a quiet, isolated room with patients sitting on an ergonomic chair with the trunk erect. After a 3-min equilibration period, EMG activity was recorded for 6 min. EMG activity was measured as the root mean square voltage[13,20] averaged over 1-min epochs. This technique had been previously validated.[21] See "Supplemental material" for details.

2.3 | Statistical analysis

Analysis of CT images and EMG recordings was performed blindly. The means (±SE) of the variables measured were calculated. The Kolmogorov–Smirnov test was used to check the normality of the data distribution. Parametric normally distributed data were compared by Student's *t*-test for paired or unpaired data; otherwise, the

Wilcoxon signed rank test was used for paired data, and the Mann–Whitney *U* test was used for unpaired data. Correlations of paired data were examined using Pearson's chi-squared test.

3 | RESULTS

3.1 | Demographics and study flow

One hundred thirty-nine patients (130 women, 9 men; age range: 19–79 years) participated in the studies. All patients had a functional disorder diagnosis based on Rome II or III criteria; of note, all patients but four (with alternating IBS), fulfilled criteria of constipation-predominant IBS or functional bloating[22,23] (Table 1).

Measurements of patient's rating of visible abdominal distension (by scales) and girth (by tape measure) were obtained in all patients (see reproducibility data in Supplemental material). Abdominal CT imaging (including anterior wall, diaphragm, and abdominal content) was obtained in 104 patients; in 47 patients, imaging also included the thorax (abdominothoracic CT scans). EMG recordings of the abdominothoracic muscles were performed in 76 patients (anterior wall and intercostals); diaphragmatic activity was obtained in 35 patients. Forty-one patients underwent both CT imaging and EMG recordings. No differences in demographic and clinical characteristics were found in patients who underwent CT scanning, electromyography, or both (Table S1).

3.2 | Is abdominal distension real?: Changes of the anterior abdominal wall

Following the study instructions, in the study day corresponding to an episode of abdominal distension, all patients rated visible abdominal distension more severe than in the visit corresponding to basal conditions (4.9 ±0.1 vs 1.8 ±0.1 score; respectively; $p < 0.001$). Objective proof of abdominal distension was gathered by three lines of evidence, as follows.

(a) Girth measured by tape measure ($n = 139$) was larger during episodes of abdominal distension than during basal conditions (by 24 ± 1 mm) in all patients but one, who exhibited a minor decrease in girth (by 6 mm).

TABLE 1 Demographics and Clinical data

	Functional bloating	Irritable bowel (IBS)
N	61	78[a]
Age (range), y	47.5 (19–72)	49.4 (21–79)
Sex, F/M	57/4	73/5
Symptom duration, y	7.2 ± 1.6	6.7 ± 1.2
Bowel habit, n/wk.	4.8 ± 0.6	5.5 ± 0.5
Stool form, Bristol score	4.1 ± 2	3.6 ± 0.4

[a]74 constipation-predominant and 4 with alternating bowel habit.

(b) Muscular activity of the anterior abdominal wall, measured at the level of the internal oblique by EMG ($n = 76$), was lower (indicative of reduced tone) during episodes of abdominal distension than during basal conditions (by 45 ± 2%) in all but 3 patients (group A in Figure 2).

(c) Abdominal perimeter measured by CT ($n = 104$) was larger during episodes of distension than on the basal scan in 96 patients (by 31 ± 2 mm), did not change in 2 patients, and was smaller in 6 (by 9 ± 4 mm); to note, the magnitude of the decrease in the latter was considerably smaller than the magnitude of the increase in the former (absolute change; $p = 0.010$). The 8 patients with no change or smaller perimeter during distension (group B in Figure 3) did no exhibit distinctive characteristics as compared to the rest: all 8 patients exhibited an increase in girth by tape measure (by 22 ± 5 mm), and the differences from basal in intestinal gas (56 ± 21 ml increase) and in the position of the diaphragm (11 ± 7 mm descent) were similar as in the 96 patients with perimeter increase by CT (58 ± 11 ml gas increase and 11 ± 2 mm diaphragmatic descent).

3.3 | Is abdominal distension related to an increase in intestinal gas?

Intestinal gas volume in the distension scans was within ±300 ml from that measured in the baseline scans in all but 5 patients, in whom the difference was above that range; these 5 patients exhibited an increase in abdominal perimeter similar to the rest (group A in Figure 3), and despite the larger gas volumes, they exhibited a diaphragmatic descent (group A in Figure 4) indicative of abdominophrenic dyssynergia (Figure 1).

Total intraabdominal content decreased in 10 patients (group A in Figures 5 and 6), increased less than 1500 ml in 86 patients and more than that in 8 patients (group B in Figures 5 and 6); no differences in the changes of abdominal perimeter (Figure 5) and diaphragmatic position (Figure 6) were observed between the three groups.

3.4 | Is abdominal distension produced by a diaphragmatic push (abdominophrenic dyssynergia)?

(a) The activity of the diaphragm measured by EMG ($n = 35$), was more intense (more tone) during episodes of abdominal distension than during basal conditions (by 50 ± 7%) in all patients but one (8% decrease).

(b) The position of the diaphragm measured by CT ($n = 103$; diaphragmatic dome not visible in 1 scan) was lower during episodes of abdominal distension than in the basal scan in 82 patients (17 ± 2 mm descent) and above in 21 patients (12 ± 3 mm ascent) (Figure 4); to note, in both groups, changes in abdominal perimeter associated with distension (increase by 22 ± 3 vs 30 ± 3 mm, respectively; $p = 0.110$) and abdominal gas (Figure 4) were similar. This lack of differences also applied to the extreme cases with more pronounced diaphragmatic ascent (group B in Figure 4) or descent (group C in Figure 4).

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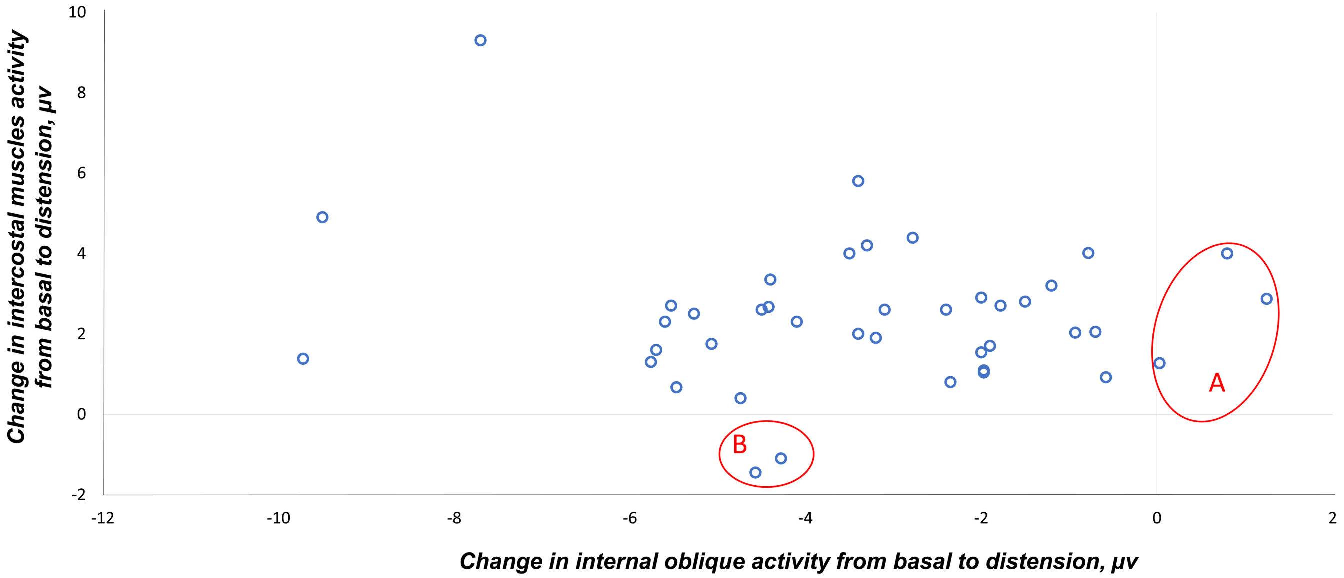

FIGURE 2 Changes in abdominothoracic muscular activity by EMG from basal to distension ($n = 76$). The activity of the internal oblique, most representative of the activity of the anterior wall, was reduced in all but 3 patients (group A), and the activity of the intercostal muscles increased in all but 2 (group B)

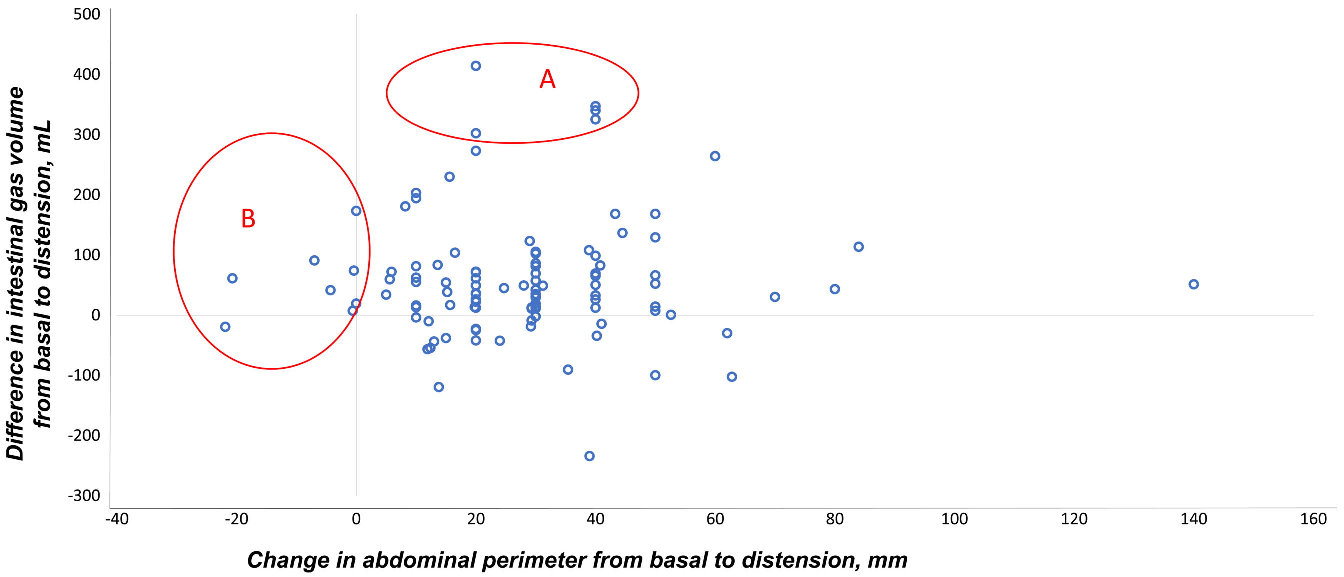

FIGURE 3 Changes in intestinal gas and abdominal perimeter by CT from basal to distension ($n = 104$). The abdominal perimeter was larger in the distension scan than on the basal scan in all but 8 patients (group B). In the distension scans, intestinal gas volume was within ±300 ml from basal in all but 5 patients with a larger increment (group A)

3.5 | Ancillary observation: involvement of the chest

(a) The activity of the intercostal muscles measured by EMG ($n = 76$) increased during episodes of distension as compared to basal conditions (by 47 ± 5%) in all but 2 patients (<12% decrease; group B in Figure 2); to note, the physiological action of intercostal contraction is elevation of the costal wall and expansion of the chest.

(b) Anteroposterior diameter of the chest measured by CT (in abdominothoracic scans; $n = 47$), increased during episodes of distension as compared to basal conditions (by 13 ± 3 mm) in all but 4 patients, who nevertheless exhibited a diaphragmatic descent.

(c) Pulmonary air volume measured by CT ($n = 47$) increased during the distension episodes as compared to basal conditions (by 491 ± 83 ml) in all but 6 patients.

4 | DISCUSSION

Our study shows that in most patients complaining of self-limited episodes of visible abdominal distention: (a) their claim is substantiated

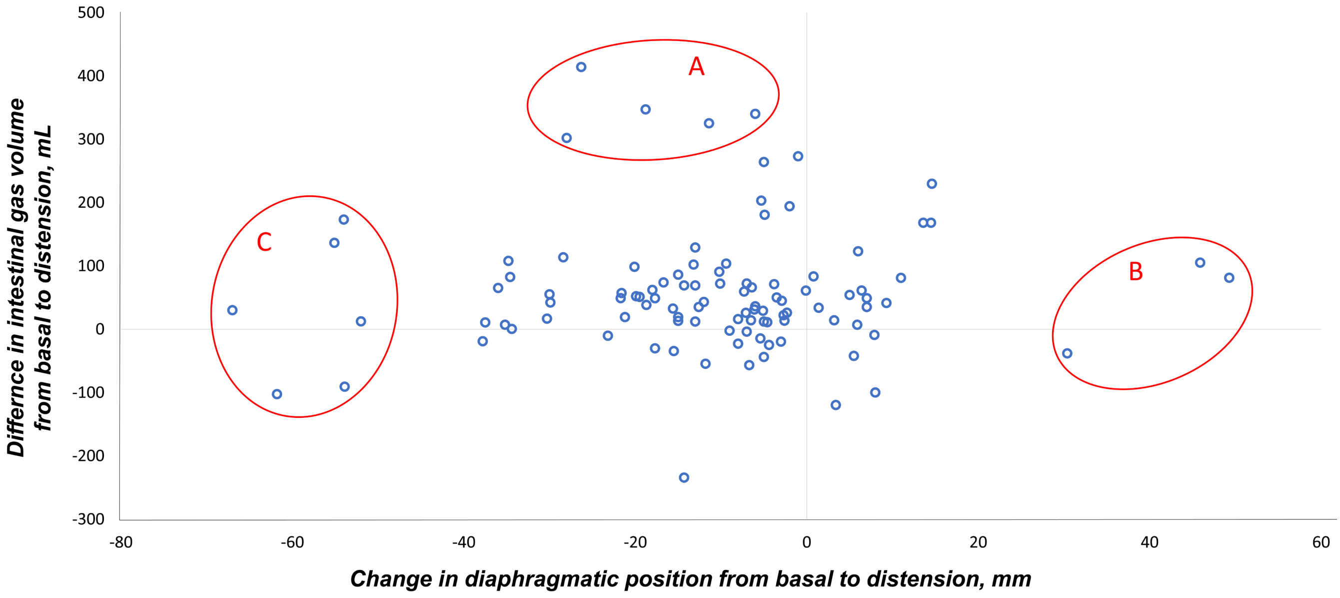

FIGURE 4 Changes in intestinal gas and diaphragmatic position by CT from basal to distension (*n* = 103). The 5 patients with a > 300 ml increase in gas during distension (group A) exhibited diaphragmatic descent. During episodes of abdominal distension, the diaphragm was below basal conditions in 82 patients and above in 21 patients (diaphragmatic dome not visible in 1 scan). Note similar changes in intestinal gas regardless of changes in diaphragmatic position, even in extreme cases with more pronounced diaphragmatic ascent (group B) or descent (group C)

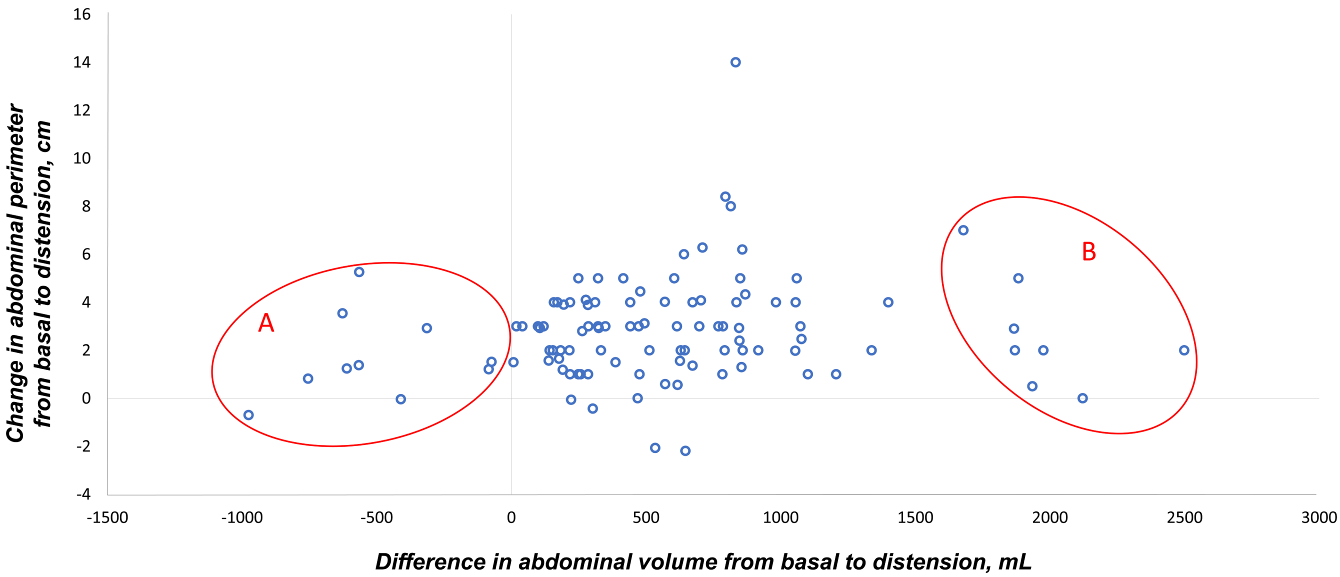

FIGURE 5 Changes in abdominal content and abdominal perimeter by CT from basal to distension (*n* = 104). Total abdominal volume decreased in 10 patients (group A) and increased less than 1500 ml in 86 patients and more than that in 8 patients (group B); no differences in the changes in abdominal perimeter were observed between the three groups

by objective evidence, (b) an increase in intestinal gas does not justify visible abdominal distention, and (c) abdominophrenic dyssynergia can be consistently evidenced by dynamic functional studies; static imaging largely confirms this mechanism of distention but bears some limitations in the evaluation of the diaphragm.

A previous study evaluating patients with functional gut disorders failed to detect differences in abdominal circumference between those who reported visible abdominal distension versus those who did not.[24] Since visible abdominal distension is intermittent, that is, blows up during discrete episodes and remits, distension may be missed at the time of the consultation, and physicians are frequently confronted with a normal examination. In this case, the patient may be instructed to return when they are distended, but our study suggests that this may not be necessary, because with proper interrogation, patients reliably recognize episodes of visible abdominal distension.

Abdominal distention is commonly attributed to excess intestinal gas by patients and their attending physicians.[1–3,6] This belief is reinforced by the fact that visible distention is usually associated with

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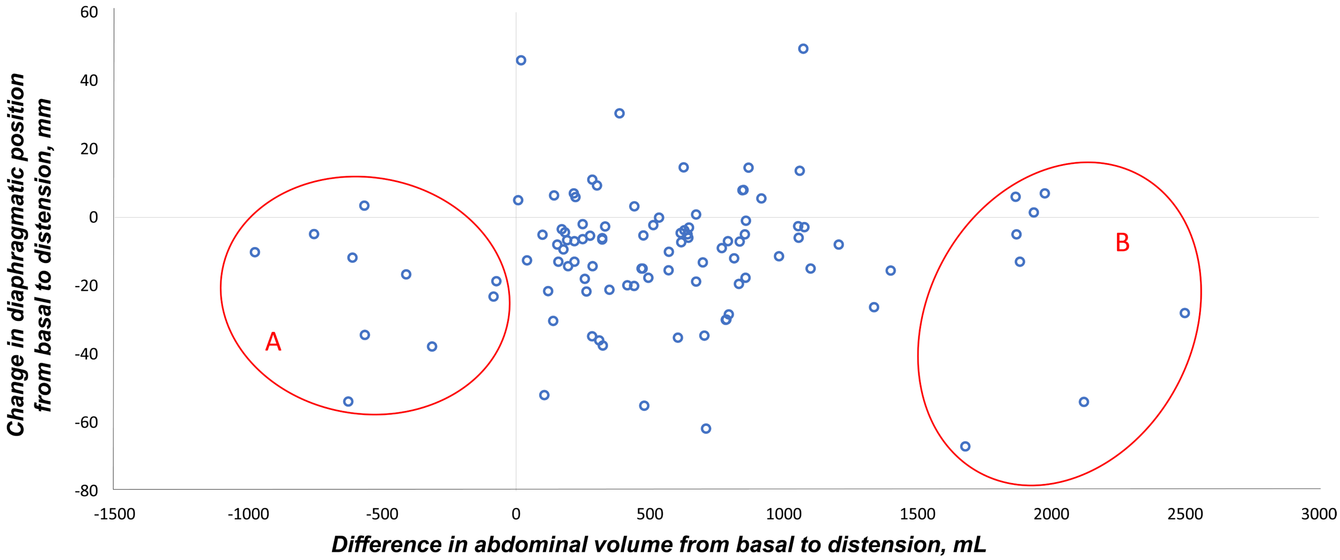

FIGURE 6 Changes in abdominal content and diaphragmatic position by CT from basal to distension. Note that regardless of the changes in total abdominal volume (decrease in group A and higher increase in group B) the changes in diaphragmatic position were in the same range

other symptoms seemingly related to gas, such as bloating sensation, defined as sensation of increased abdominal pressure/fullness, borborygmi and flatulence.[10,25] However, our study showed that visible distention in our patients was associated with an increase in gas over 300 ml in only a minority (5 out of 104 patients), and even these patients exhibited a clear pattern of abdominophrenic dyssynergia (diaphragmatic push and downwards displacement of contents). In normal conditions, the walls of the abdomen actively adapt to its content,[13,21,26] and a volume increase induces diaphragmatic relaxation and upwards expansion of the abdominal cavity with minor repercussions on the anterior wall, a phenomenon termed abdominal accommodation.[26] Hence, even the largest increase in gas observed in the minority of patients would not justify per se their visible abdominal distention (Figure 1). Furthermore, the level of distention in these patients was similar to that in the rest, suggesting that abdominophrenic dyssynergia was the key driver of distention. The same reasoning applies when considering changes in total abdominal contents.

In our patients, electromyography consistently showed that during episodes of abdominal distention, the activity of the diaphragm increased, implying a diaphragmatic descent, coupled with decreased postural tone of the anterior wall. In normal conditions, the activity of the diaphragm is counterbalanced by the costal wall, to preserve pulmonary function,[21] for example, diaphragmatic descent is compensated by descent of the costal wall. By contrast, the diaphragmatic descent detected during distension was associated with a paradoxical elevation of the costal wall, driven by intercostal contraction, and resulting in hyperinflation of the chest; this condition mimics asthmatic status and explains the shortness of breath characteristic of episodes of severe distention.

Imaging of the walls obtained by CT, evidenced the mechanical counterparts of the functional data detected by electromyography. CT detected an increase in abdominal perimeter, diaphragmatic descent, and an increase in the air volume in the chest. However, in 20% of the patients, CT failed to detect the expected diaphragm descent, but nevertheless, their abdominal perimeter increased, without a major increase in abdominal volume, and the air in the chest also increased. Considering that the abdominothoracic walls, and particularly the diaphragm, exert a postural tone with superimposed respiratory phasic activity, instantaneous CT imaging may bear limitations as compared to dynamic measurements of muscular activity (by EMG) and girth (by adaptable belts) over various respiratory cycles. Furthermore, both girth and EMG measurements were performed with the trunk erect, whereas CT scans were obtained supine, and posture-related gravitational forces have been shown to influence the adaptation of the abdominal walls to its content.[26]

We wish to acknowledge some limitations of our study. Since not all patients underwent both CT and EMG, the values of the tests cannot be compared in the whole pool of patients. Nevertheless, our data indicate that both distorted interpretation and intestinal gas accumulation, two key questions of our study, seem unlikely. The predominance of constipation-predominant IBS and functional bloating in our study population is not unexpected but may be related to a referral bias; furthermore, the vast majority of our patients were women. We acknowledge that from these data it cannot be ascertained whether the mechanism of abdominal distension in other functional digestive disorders, such as diarrhea or functional dyspepsia, or in men is the same. Our data apply specifically to patients with episodic distention, which allows comparisons between distension episodes and basal conditions, but the situation of patients complaining of continuous abdominal distention may be different.[6] Indeed, complaints of steady, unremitting distension may be due to a prominent, fatty abdomen.

Our data are relevant to the understanding and management of patients with functional gut disorders complaining of visible abdominal distention. First, patients deserve credibility and warrant medical attention; however, comparative examinations during distension versus basal conditions may be spared, when they describe self-limited episodes of visible distension. The possibility of excess gas, a common belief, is very unlikely in patients with reliable diagnosis of a functional gut disorder,[27,28] and gas measurements by CT or MRI imaging can be reserved for doubtful cases. Abdominophrenic dyssynergia seems to be the rule in the majority of patients, and evidence by comparing imaging studies and/or electromyography may be required very rarely. Furthermore, CT imaging presents limitations for individual diagnosis, and adapted EMG may not be readily available. The fact that these patients respond to biofeedback therapy[9,10] indicates that this is a conditioned behavioral response; however, the conditioning mechanism and the trigger (i.e., why the patients do it) are not known. Gas is a normal component of the colon and is well tolerated by healthy subjects but may elicit symptoms in patients with functional gut disorders.[29] Indeed, patients with functional gut disorders have a sensitive gut,[29,30] and perception of symptoms related to visceral hypersensitivity, may trigger the abnormal somatic response. Hence, treatment of abdominal symptoms by conventional therapy for functional gut disorders, including dietary interventions, would seem a reasonable first step.[31] If identifiable, other triggers could also be targeted.[32] Anxiety may play a role, particularly when hyperinflation of the chest is severe. Severe, refractory cases may require psychiatric management. Neuromodulators may benefit patients with severe symptoms, but their role in visible abdominal distension remains to be established.[33] A complex biofeedback technique has been proven useful to correct abdominal postural tone and resolve distension.[9,10] The indication of this treatment is currently restricted by its complexity and cost. When available, simpler and cheaper behavioral techniques might become the standard second-line treatment of abdominal distension for patients unresponsive to standard dietary or pharmacologic interventions.

AUTHOR CONTRIBUTIONS

Data analysis and revision of manuscript: Elizabeth Barba. *Analysis of EMG recordings*: Emanuel Burri. *Analysis of CT images*: Sergio Quiroga. *Study design*: Anna Accarino. *Study design, data interpretation, manuscript preparation*: Fernando Azpiroz. *All authors read and approved the final manuscript*.

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CONFLICT OF INTEREST

No conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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