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### Title

Long-term Follow-up of Adolescents Treated for Rumination Syndrome in an Inpatient Setting

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**Pediatric Rumination Subtypes: A Study using High Resolution Esophageal Manometry with Impedance**

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3 **Pediatric Rumination Subtypes: A Study using High Resolution Esophageal Manometry**  
4 **with Impedance**  
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10 **Running title: Pediatric rumination subtypes using HRM-MII**  
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## Abstract

**Background:** The differential diagnosis of intractable reflux in children includes rumination syndrome but confirming the diagnosis using antroduodenal manometry is invasive, costly and requires anesthesia. High resolution esophageal manometry with impedance (HRM-MII) overcomes these limitations and the goal of this study is to validate the use of HRM-MII as a diagnostic tool for rumination and to describe the subtypes of pediatric rumination.

**Methods:** We reviewed the HRM-MII tracings of 21 children presenting with symptoms of intractable reflux in whom rumination was being considered. Patients underwent a standard and post-prandial HRM-MII. Peak intraluminal esophageal pressures, baseline gastric and thoracic pressures, and the timing of the R wave relative to LES relaxations and bolus flow were recorded. Chi square analyses were used for comparison of proportions and means were compared using t-tests or non-parametric equivalent.

**Key Results:** Forty one (55.5%) primary and 33 (44.5%) secondary rumination episodes were seen. Three types of primary rumination were identified: 1) LES relaxation without retrograde flow preceding the R wave (51% of episodes); 2) LES relaxation after the R wave (20% of episodes); and 3) R waves with no LES relaxation (29% of episodes). Eleven patients had rumination episodes with a peak gastric pressure <30 mm Hg. A total of 44 (60%) rumination episodes occurred during the standard HRM-MII, and 30 (40%) occurred during or after the meal.

**Conclusions and Inferences:** HRM-MII can accurately diagnose rumination in children. We identify three types of primary rumination which may provide insight into therapeutic response.

**Key words: Rumination; Impedance; High resolution esophageal manometry; pediatrics.**

**Key Points:**

- While high resolution esophageal manometry has been used to diagnose rumination in adults, its utility in pediatrics is not known.
- We show that HRM-MII is useful to diagnose rumination in children and we identify three novel subtypes of primary rumination in children.
- The high frequency of rumination events preceded by lower esophageal sphincter relaxations raises the possibility that medications that modulate LES relaxations may improve symptoms of rumination in children

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## Introduction

Rumination is a functional gastrointestinal disorder characterized by the recurrent regurgitation of gastric contents into the mouth with spitting or reswallowing (1-6). It was initially described in children with developmental disabilities, but is now recognized in many pediatric subgroups (1, 4). Even though the clinical history is suggestive of rumination, there is symptom overlap with intractable reflux so differentiating the two can be difficult but important because the therapies differ (2, 7, 8). Making a diagnosis of rumination in children is often problematic because children may be too young or lack the developmental skills to verbalize symptoms. (8). Furthermore, androduodenal (AD) manometry which allows for visualization of R waves which are pathognomonic for rumination is invasive, costly and requires catheter placement under anesthesia (2, 6, 8-10). Therefore, the diagnosis of rumination is often given presumptively rather than confirmed by testing which may lead to patient/parental questioning of the diagnosis and its associated therapies (2, 6, 8).

Studies in adults have shown that, in lieu of AD manometry, high resolution esophageal manometry (HRM) can be used to diagnose rumination by visualization of R waves when pressure sensors are placed into the stomach and esophagus(7, 11-13). The addition of impedance to HRM (HRM-MII) has also allowed for the visualization of bolus movement relative to the R waves, a significant advantage over standard AD manometry (11-13).

The use of HRM-MII is appealing in pediatrics because the study can be performed over an hour, it does not require anesthesia, and the patient/family can see the R waves which provides visual credibility for the diagnosis (7). HRM-MII may also provide insight into the mechanism of rumination in children. It is the goal of the present study to determine the feasibility of using HRM-MII to diagnose rumination in children and to describe the rumination subtypes in children.

## Methods



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3 gastric and thoracic pressures were also measured at least 30 seconds before an R wave, and  
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5 30 seconds after a swallow with its associated LES relaxation. Finally, the timing of the R wave  
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7 relative to LES relaxation and to bolus flow detected by impedance was recorded. Successful  
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9 rumination was defined as the presence of R waves and simultaneous retrograde bolus flow by  
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11 MII across the LES (4).  
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14 Transient Lower Esophageal Relaxations (TLSEs) were defined as previously  
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16 described (14). Impedance tracings were analyzed for the occurrence of reflux episodes  
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18 according to previously published criteria (15). Briefly, a liquid reflux episode detected by  
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20 impedance was defined as a retrograde drop in impedance by more than 50% of baseline in the  
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22 distal 2 channels. A gas reflux episode was defined as a simultaneous increase in impedance in  
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24 2 consecutive channels to greater than 8000 ohms. (15).  
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### 29 *Rumination episodes*

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33 Rumination episodes were categorized as primary if the R wave triggered bolus  
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35 movement into the esophagus (Figure 1-3) or secondary if the R wave occurred after the onset  
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37 of bolus movement into the esophagus (Figure 4) (11, 12, 16). Supragastric belch was defined  
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39 by the presence of an aboral movement of the diaphragm that creates a sub-atmospheric  
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41 pressure in the esophageal body and concurrent UES relaxation (12). Unsuccessful rumination  
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43 was defined as episodes in which there were clear R waves present without associated LES  
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45 relaxation or bolus movement (Figure 5b) in the absence of a recorded cough. A  
46  
47 gastroesophageal reflux episode was defined if there was evidence of LES relaxation with  
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49 retrograde bolus, and no evidence of R waves (Figure 5a). (4, 11). Cough episodes were  
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51 defined as simultaneous gastric and esophageal contractions with a concomitant clinical cough  
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53 observed and noted during the study (4, 11).  
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3 Each rumination event was scored for the following variables (12): (1) the presence of R  
4 waves; (2) The peak pressure amplitude and duration of the R wave in the abdomen (2 cm  
5 below the LES ) and the thorax (3 cm above the LES); (3) the gastric-thoracic pressure  
6 gradients before and during the rumination episodes; (4) the time between R waves and  
7 esophageal bolus entry; (5) the time between LES relaxations and R waves; (6) the time from  
8 LES relaxation to bolus entry; (7) the sequence of bolus entry relative to gastric pressure  
9 increases; and (8) the maximum height of the retrograde flow.  
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### 20 *Statistics*

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22 Data are presented as medians and range or mean and SE depending on the variable  
23 distribution. Statistical analysis was performed using SPSS version 23. Comparisons between  
24 proportion were used using chi-square, and between continuous variables paired tests,  
25 independent t-tests or non-parametric statistics when applicable. Differences were considered  
26 statistically significant when  $P < 0.05$ .  
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### 36 **Results**

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38 Twenty one patients were included. There were 15 females. The mean age of the  
39 patients was  $15 \pm 4.9$  years (range 7 to 18 years). Post-prandial regurgitation was present in  
40 100% of patients, nausea in 30%, heartburn in 50%, intractable reflux in 70%, and chest pain in  
41 20%. All patients continued to have symptoms despite twice daily PPI therapy. All had a grossly  
42 normal upper endoscopy with no visible erosions, normal esophageal biopsies with no  
43 eosinophilic infiltration, and a normal esophageal manometry by Chicago classification (17)  
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51 Rumination episodes were seen in 18/21 patients. Of the three patients without  
52 rumination, one patient had R waves but no retrograde bolus movement into the esophagus  
53 (unsuccessful rumination, Figure 5b) and two patients had LES relaxations with retrograde  
54 bolus movement without R waves (gastroesophageal reflux, Figure 5a). Therefore, in three  
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3 patients, HRM-MII disproved the diagnosis of rumination. The following analysis includes only  
4 those 18 patients with documented rumination  
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### 7 ***Rumination episodes:***

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10 There were 74 rumination episodes seen in 18 patients. The characteristics of the  
11 rumination episodes are seen in Table 1. No episodes of supragastric belching were seen.  
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13 There were 41 (55.5%) primary and 33 (44.5%) secondary rumination episodes. Thirteen  
14 patients had both primary and secondary episodes of rumination, 3 had only primary episodes,  
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16 and 2 had only secondary rumination episodes.  
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21 A comparison primary and secondary rumination characteristics is shown in Table 1.  
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23 During secondary rumination episodes, the LES nadir during relaxation was significantly lower  
24 and the peak R wave pressures in chest and stomach were higher compared to primary  
25 rumination episodes. Additionally, during secondary rumination, UES nadir pressures were  
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27 lower and proximal bolus migration was higher compared to primary rumination.  
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32 In addition to categorizing ruminations episodes as primary versus secondary, we also  
33 discovered three **distinct patterns of primary rumination** 1) L-R-F (LES relaxation followed  
34 by R wave and bolus flow, Figure 1); 2) R-L-F (R wave followed by LES relaxation and bolus  
35 flow, Figure 2); and 3) N-R-F (no LES relaxation but R waves and bolus flow, Figure 3 a and b).  
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37 A comparison of the main characteristics of each type of primary rumination episodes is shown  
38 in Table 2. Not all patients had all types of primary rumination. Only 16 had primary rumination  
39 events. Of those 16, five had only type L-R-F primary rumination, two only had type R-L-F, and  
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41 one had NR-F. The other 8 patients had a combination of primary rumination types.  
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### 51 ***Characteristics of the R waves.***

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53 In 11 patients, the pressure of the R wave was < 30 mmHg (range 19-27). Given that the  
54 adult definition stipulates that the R waves needs to have 30 mmHg (12), we compared the  
55 rumination episode characteristics between those with a R wave pressure of < 30 mm Hg and  
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3 those with R waves > 30 mm Hg. As expected there was a significant difference in the peak R  
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5 wave between both groups ( $23 \pm 1.2$  mm Hg vs.  $80 \pm 4.7$  mm Hg,  $p < 0.004$ ). There was no  
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7 difference in the duration of the R wave, the type of rumination, or the sequence of esophageal  
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9 events ( $p > 0.1$ ). The only other significant difference we found was in the time it took for the  
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11 retrograde bolus to start after the R wave ( $0.9 \pm 0.5$  vs.  $0.13 \pm 0.11$  sec;  $p < 0.04$ )  
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### 14 15 16 ***Comparison between rumination events during stationary manometry vs during a meal*** 17

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19 A total of 44 (60%) rumination episodes occurred during the standard HRM-MII, and 30  
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21 (40%) occurred after the meal. In 9/18 (50%) patients, the rumination events occurred only  
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23 during the standard HRM-MII, in 3/18 (17%) patients, the rumination events occurred during  
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25 both the standard HRM-MII and after the meal, and, in 6/18 (33%) patients, the rumination  
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27 events occurred only after the meal.  
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30 Table 3 compares the rumination characteristics of episodes that occurred during the  
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32 standard HRM-MII to those that occurred after the solid meal; as seen in the table, rumination  
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34 episodes occurring after the meal were accompanied by more preceding LES relaxations and  
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36 with lower R wave pressures and duration as compared with those that occurred after liquid  
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38 swallows.  
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### 40 41 42 **Discussion:** 43

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45 This is the first study to (1) prove that HRM-MII is a useful tool to diagnose (or exclude  
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47 rumination) in children; and (2) define rumination subtypes relative to LES relaxations. Our  
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49 study suggests that the majority of rumination episodes in children immediately follow an LES  
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51 relaxation, even when it is not associated with a reflux event, a finding that has not been  
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53 previously described either in adults or children. This latter finding may be of particular  
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55 importance as therapies which target LES relaxations may be beneficial in subtypes of  
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57 rumination patients.  
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3 The diagnosis of rumination can be difficult (2, 8) with patients often undergoing  
4 extensive and costly work up including AD manometry (2, 8). AD manometry is only performed  
5 in a few tertiary centers, is invasive, and does not establish the relationship between the  
6 generated abdominal pressure and the retrograde bolus flow into the esophagus. Therefore the  
7 present study is important because it highlights that HRM-MII can be used to successfully  
8 diagnose (and even disprove) rumination in children referred for intractable regurgitation. This  
9 ability to prove or disprove a diagnosis highlights the value of HRM-MII which not only can  
10 detect R waves but also can detect bolus flow using impedance; in our series, 15% of patients  
11 with a possible diagnosis of rumination actually has significant reflux or abdominal contractions  
12 without the presence of bolus movement into the esophagus, a condition that would have been  
13 missed by antroduodenal manometry or HRM without impedance.  
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27 Current adult definitions of primary or secondary rumination are based on the timing of R  
28 wave relative to bolus flow. In adults, secondary rumination is common, making up as much as  
29 86% of all rumination episodes (7, 11, 12) and, in these episodes, the pathophysiology is more  
30 clear; patients sense bolus movement into the esophagus which then triggers R waves (4, 7, 11,  
31 12). In our study, unlike in adult studies, secondary rumination episodes only made up 45% of  
32 pediatric rumination episodes so clearly a better understanding of the pathophysiology of  
33 primary rumination becomes more important. We identified three distinct subtypes of primary  
34 rumination: (1) L-R-F: those with LES relaxation prior to R waves and bolus flow; (2) R-L-F.:  
35 those with LES relaxation following R waves and bolus flow; and (3) N-R-F: R waves without  
36 LES relaxation. We found that almost 50% of the primary rumination episodes occurred after  
37 an isolated LES relaxation event. This is much more rare in adults; a single adult study reports  
38 that this pattern is only seen in 11% of rumination events (11). These differences suggest that  
39 the mechanisms underlying rumination in children may be different than adults and we  
40 hypothesize that these LES relaxation events trigger sensory feedback independently of bolus  
41 flow which results in the need to ruminate. Studies in adults support a sensory mechanism for  
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3 rumination; patients may have increased gastric sensitivity and other associated esophageal  
4 sensory abnormalities (4, 18). In fact a previous study showed that during esophageal HRM  
5 studies 72% of adult patients spontaneously reported sensory based symptoms such as  
6 dyspepsia before the appearance of R waves with resolution of symptoms once gastric contents  
7 reach the mouth.  
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14         These sensory abnormalities may also be associated with gastric motor abnormalities.  
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16 Studies in adult suggest that gastric distension may results in more LES relaxations, and a  
17 lower LES relaxation nadir in patients that ruminate. (18). Other studies suggest that there is  
18 poor postprandial gastric accommodation and a disruption of normal abdominothoracic activity  
19 after meals which result in increased numbers of LES relaxations (6). Therefore rumination  
20 patients may have a hypersensitive response to LES relaxation, either related to the relaxation  
21 itself or due to an LES relaxation-triggered common cavity phenomena that generates the R  
22 wave as an attempt to relieve abnormal sensation, or dyspeptic symptoms (4, 11). Because the  
23 patients experience relief of symptoms with the regurgitation of gastric contents, they  
24 unconsciously adopt a sequence of learned behaviors that produces the rumination event to  
25 relieve symptoms (2).  
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38         Further supporting this possibility that LES relaxations trigger an uncomfortable  
39 sensation which triggers the urge to ruminate, we found that 40% of patients experienced some  
40 type of sensation before the R wave occurred across all types of rumination. In 6 patients with  
41 primary rumination in which there was LES relaxation prior to generation of R waves (type L-R-  
42 F), the patients described a sensation of pressure before the R wave, and then produced the R  
43 wave and retrograde flow to relieve the pressure. In all cases the discomfort disappeared.  
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51         While the LES relaxation may play an important role in the sensation that triggers a  
52 rumination episode, we also found that up to a third of primary rumination episodes occurred  
53 without true LES relaxations. We did see subtle drops in LES pressures but no complete LES  
54 relaxation and this was unexpected based on studies in healthy adult volunteers which actually  
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3 show increases LES pressures with rises in abdominal pressure (19). This finding of rumination  
4 through a closed LES is a novel finding and in fact, adult studies have documented the  
5 importance of LES relaxation as a prerequisite to regurgitation of gastric contents (18, 20). It is  
6 possible that those patients in which regurgitation of gastric contents occurs without LES  
7 relaxation represent a different type of underlying pathophysiology, and may have more  
8 behavioral or psychiatric comorbidities as a trigger rather than a sensory dysregulation.  
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16 The subtyping of rumination events may allow for improved predictions for which  
17 patients will respond favorably to different therapies. (4, 5, 11) While limited adult and pediatric  
18 studies suggest that response to behavioral therapy or diaphragmatic breathing is generally  
19 positive in up to 50% of patients (2, 4, 6, 11), some patients do not respond and some patients  
20 are ineligible for behavioral therapies because of developmental/neurologic comorbidities. (2, 4,  
21 5). We postulate that the presence/absence of LES relaxations and their type of association with  
22 the R waves may predict response to therapy; for example, in the subgroup of patients in whom  
23 LES relaxations precede the R wave, mediations that modulate LES relaxation may be  
24 beneficial. In fact recent evidence in adults has shown that the use of baclofen, an agonist of the  
25  $\gamma$  aminobutyric acid (GABA)<sub>B</sub> acid receptor, increases LES basal pressures and decreases  
26 TLSEs and swallowing rate; this may decrease symptoms and reduce retrograde bolus flow in  
27 patients with rumination (21). Baclofen has similarly been shown, in pediatric GERD patients,  
28 (22) to decrease TLSEs and improve gastric emptying both of which may be beneficial in the  
29 patients with LES relaxation-predominant rumination. (23).  
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46 Apart from the novel subtypes of primary rumination that we describe in this study, there  
47 are two other important points to highlight in our results. First, we report that children are able  
48 to ruminate with gastric pressures as low as 20 mmHg, so adult centers performing  
49 manometries in children will need to revise their definition of rumination episodes for the  
50 pediatric patients. (12, 16). Second, we found that more than a third of rumination episodes only  
51 occurred after administration of a meal so patients would have been incorrectly diagnosed 33%  
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3 of the time if only stationary manometry had been performed. Our findings are similar to some  
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5 previous studies in adults in which rumination was demonstrated in 48% after the water  
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7 swallows, 15% after the first 200-mL water swallow and in 37% after the test meal (11). The fact  
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9 that a solid meal is necessary to produce rumination episodes is not a surprising finding given  
10  
11 the abnormal gastric accommodation that has been described in these patients.(6, 18).  
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14 Therefore, for all children with suspected rumination, HRM-MII should include both a standard  
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16 manometry as well as a post-meal manometry.  
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19 One of the limitations to our study is that we studied patients only for 30 minutes after a  
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21 meal so some episodes of rumination may have been missed with this length of observation.  
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23 For the three patients in whom rumination was not seen, it is possible that longer observation  
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25 periods may be needed to capture episodes. Additionally, the predominant types of  
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27 ruminations episodes may shift as the time away from the meal lengthens and this merits  
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29 additional study.  
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32 In conclusion, we have shown the HRM-MII is an ideal tool to diagnose rumination in  
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34 children because of its short duration and noninvasive nature. We have documented both  
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36 primary and secondary rumination in children and most importantly, we suggest a new  
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38 classification of primary rumination based on the R wave presence relative to LES relaxation.  
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40 Future studies are needed to determine if these subtypes predict therapeutic response.  
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8  
9

10 **Authors' contribution:**

11  
12 RR participated in the design of the study, performed the manometry studies, performed the  
13 analyses, drafted the manuscript and approved of the final version.  
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15  
16 LR performed the manometry studies, drafted the manuscript and approved of the final version.  
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18  
19 SN participated in the design of the study, performed the manometry studies, performed the  
20 analyses, drafted the manuscript and approved of the final version.  
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3 Abbreviations:  
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5 TLESR: Transient lower esophageal sphincter relaxation  
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7 HRM-III: High resolution esophageal manometry with impedance  
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9 LES: Lower esophageal sphincter  
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Table 1. Comparison between primary and secondary rumination episodes (means±SE unless indicated).

	Total Rumination Episodes	Primary Rumination	Secondary Rumination	p Value
N (%)	74	41 (55.4)	33 (44.5)	0.3
<b>LES baseline pressure (mmHg)</b>	<b>26.5 ± 1.3</b>	24.9 ± 1.3	27.8 ± 1.9	0.2
<b>LES pressure during rumination episode (mmHg)</b>	<b>5.3± 1.1</b>	7.2 ± 1.1	2.7 ± 0.9	0.04
<b>Gastric pressure before R wave (mmHg)</b>	<b>10.8 ± 0.4</b>	10.6 ± 3.5	11.1 ± 3.4	0.6
<b>Gastric pressure during R wave (mmHg)</b>	<b>71.2± 4.7</b>	62.1± 5.9	79.5 ± 6.7	0.05
<b>Duration of gastric R wave (sec)</b>	<b>0.6 ± 0.1</b>	0.5 ± 0.7	0.7 ± 0.2	0.4
<b>Difference in baseline gastric pressure and Peak R wave pressure (mmHg)</b>	<b>61.2±4.7</b>	51.4 ± 6.1	68.9 ± 6.7	0.04
<b>Thoracic pressure before R wave (mmHg)</b>	<b>-0.2 ± 0.4</b>	-0.3 ± 0.5	0.5 ± 0.6	0.5
<b>Thoracic pressure during R wave (mmHg)</b>	<b>51.0± 4.3</b>	40.5 ± 4.2	59.3 ± 6.7	0.02
<b>Difference in baseline thoracic pressure and peak R wave pressure (mmHg)</b>	<b>51.0±4.4</b>	40.7±4.4	59.1 ± 6.9	0.04
<b>Difference in gastric pressure and thoracic pressure during baseline (mmHg)</b>	<b>10.7±0.4</b>	10.9 ± 0.6	10.5 ± 0.6	0.8
<b>Difference in gastric pressure and thoracic pressure during rumination (mmHg)</b>	<b>20.1 ± 2.8</b>	20.1±3.4	21.6 ± 4.5	0.7
<b>Mean time from R wave to Bolus Entry (sec)</b>	<b>0.8±0.2</b>	0.2 ± 0.1	0.4 ± 0.2	0.02
<b>Mean time LES relaxation to bolus entry (sec)</b>	<b>3.2±1.1</b>	4.4 ± 1.8	2.8±1.1	0.3
<b>Mean time from LES</b>	<b>4±1.1</b>	3.7±1.3 (only	4.4±1.9	0.7

<b>relaxation to R wave (sec)</b>		those with LES relaxation)		
<b>Time of bolus presence in the esophagus to R wave (sec)</b>	<b>0.8±0.9</b>	0.05 ± 0.1	1.5 ± 0.4 before the R wave	0.003
<b>Duration of bolus presence in the esophagus (sec)</b>	<b>4.4±0.8</b>	5.9 ± 1.4	3.1 ±0.9	0.08
<b>Sensation before R wave (%)</b>	<b>39</b>	42	39	0.3
<b>UES opening during rumination (%)</b>	<b>84</b>	78	97	0.004
<b>Bolus reaching UES during rumination (%)</b>	<b>64</b>	58	78	0.06
<b>Rumination episodes during meal (%)</b>	<b>44</b>	44	36	0.3

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Table 2 Comparison between types of primary rumination.

	<b>Type L-R-F (LES relaxation-R wave-Bolus Flow)</b>	<b>Type R-L-F (R wave-LES relaxation- Bolus Flow)</b>	<b>Type N-R-F (no LES relaxation-R wave-Bolus Flow)</b>
<b>Number of Primary Rumination Episodes (%)</b>	21 (51)	8 (20)	12 (29)
<b>LES baseline pressure (mmHg)</b>	29.1 ± 2.7	22.7 ± 3.1	29.3 ± 4.4
<b>LES pressure during rumination episode (mmHg)</b>	7.2 ± 1.9	6.5 ± 1.8	16.0 ± 2.4
<b>Gastric pressure before R wave (mmHg)</b>	10.0 ± 0.6	14.0 ± 1.1	10.7 ± 8.3
<b>Gastric pressure during R wave (mmHg)</b>	82 ± 8.6	89.8 ± 16.7	71.3 ± 14.2
<b>Duration of gastric R wave (sec)</b>	0.7 ± 0.2	0.5 ± 0.2	0.8 ± 0.4
<b>Difference between baseline gastric pressure and peak R wave gastric pressure (mmHg)</b>	72.9 ± 8.8	76.1 ± 17.0	61.0 ± 14.0
<b>Thoracic pressure before R wave (mmHg)</b>	-0.6 ± 0.9	3.3 ± 1.2	-0.3 ± 1.0
<b>Thoracic pressure during R wave (mmHg)</b>	55.0 ± 8.6	71.5 ± 16.4	61.0 ± 15.0
<b>Difference between baseline thoracic pressure and peak R wave thoracic pressure (mmHg)</b>	55.6 ± 8.6	70.0 ± 19.1	61.1 ± 15.1
<b>Difference between baseline gastric pressure and thoracic pressure at baseline (mmHg)</b>	10.5 ± 1.1	10.6 ± 1.3	11.0 ± 0.7
<b>Difference between gastric pressure and thoracic pressure during rumination (mmHg)</b>	27.0 ± 5.3	18.4 ± 4.7	10.6 ± 0.7
<b>Mean time from R wave to bolus entry (sec)</b>	0.2 ± 0.1	0.5 ± 0.3	0.1 ± 0.1
<b>Mean time LES relaxation to bolus entry (sec)</b>	6.0 ± 2.0	-0.2 ± 0.2	No relaxation
<b>Mean time from LES relaxation to start of R wave (sec)</b>	6.0 ± 2.5 before R wave	0.3 ± 0.5 after R wave	No relaxation
<b>Time from bolus presence in the esophagus to R wave (sec)</b>	17 episodes simultaneous 4.35 ± 1.84 sec with 4 episodes after R	0.5 ± 0.3 after R wave	0.1 ± 0.1 after R wave

<b>Duration of bolus presence in the esophagus (sec)</b>	4.3± 7.8	2.6± 3.4	1.1± 1.8
<b>Percentage of episodes sensed by patient prior to rumination</b>	33	62	33
<b>UES opening during rumination (%)</b>	86	75	64
<b>Bolus reaching UES during rumination (%)</b>	52	88	46
<b>During meal (%)*</b>	33	87	33

\*P=0.02

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Table 3. Differences in rumination characteristics that occur after liquid swallows and after a meal.

	Liquid swallow	After solid meal	P value
Age	15.7 + 1.9	13.8 + 4.2	0.9
Number of Episodes	44	30	0.4
Number of Primary Rumination Episodes	23	18	0.5
Number of Secondary Rumination Episodes	21	12	
LES Pressure Prior to Rumination (mmHg)	26.9 + 1.8	26.0 + 1.4	0.4
Time from R Wave to Bolus Entry (sec)	-0.12 + 0.2	0.1 + 0.1	0.5
Time from LES relaxation to start of R wave (sec)	6.5 + 1.8	0.36 + 0.2	0.006
Time from LES Relaxation to Bolus Entry (sec)	5.4 + 1.7	0.04 + 0.7	0.01
Time from Bolus to Peak R wave Pressure (sec)	1.2 + 0.4	0.3+0.2	0.06
Gastric pressure before Rumination (mmHg)	10 + 0.5	12.0 + 0.6	0.013
Thoracic pressure before Rumination (mmHg)	-0.64+0.5	1.0+0.7	0.049
Peak Gastric Pressure during R Wave (mmHg)	79.6 + 7.3	61.4 + 3.9	0.03
Peak Thoracic Pressure during R Wave (mmHg)	55.2+ 6.9	54.5 + 3.8	0.3
Duration of R Wave (sec)	0.9 + 0.2	0.1 + 0.1	0.001
% of Rumination Episodes with LES relaxation before R	40%	73%	0.03
% of Rumination Episodes associated with UES Relaxation	64%	68%	0.5
Gastric pressures during R wave < 30 mmHg	18%	10%	0.2
<b>Subtypes of Primary Rumination (N)</b>			
L-R-F	79	57	<0.006
RLF	2	26	
NRF	18	16	

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10 Table 1. Comparison between primary and secondary rumination episodes (means±std  
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13 Table 2 Comparison between types of primary rumination.

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15 Table 3. Differences in rumination characteristics that occur after liquid swallows and  
16 after a meal.

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18 Figure 1. Primary rumination with LES relaxation prior to R wave (L-R-F subtype).

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20 Purple denotes fluid flow by impedance. There is no retrograde flow until the R wave  
21 occurs even though there is preceding LES relaxation.  
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25 Figure 2. Primary rumination with R wave preceding LES relaxation (R-L-F subtype).

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27 Purple denotes fluid flow by impedance.

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29 Figure 3. Primary rumination with R wave with no LES relaxation (N-R-F subtype).

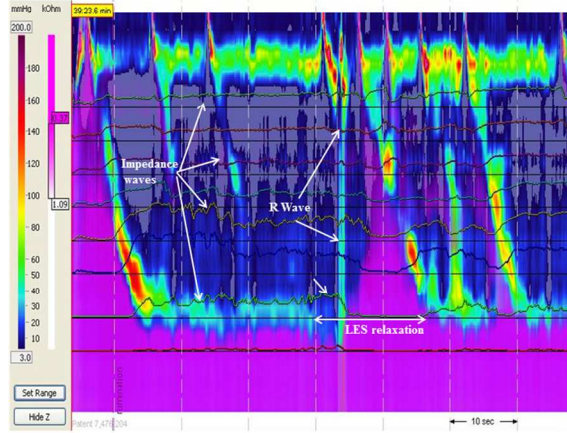
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31 Purple denotes fluid flow by impedance. The figures represent the same rumination  
32 episodes without (a) and with (b) the purple impedance added to show bolus flow  
33 despite a closed LES.  
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37 Figure 4. An example of secondary rumination. There is LES relaxation with retrograde  
38 flow before the R wave occurs.  
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42 Figure 5. Examples of episodes where HRM-MII disproved rumination including reflux  
43 episodes with a TLESR and retrograde bolus flow (a) and generation of R waves  
44 without bolus flow. Purple represents liquid by impedance.  
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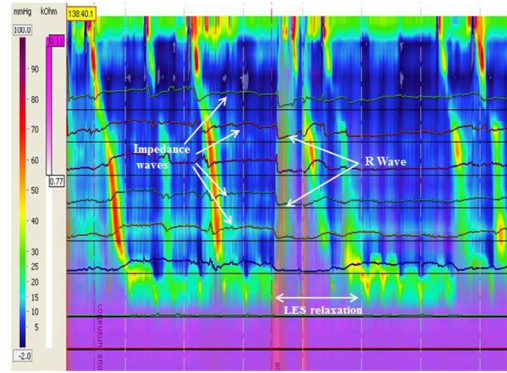
Figure 1. Primary rumination with LES relaxation prior to R wave (L-R-F subtype). Purple denotes fluid flow by impedance. There is no retrograde flow until the R wave occurs even though there is preceding LES relaxation.



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Figure 2. Primary rumination with R wave preceding LES relaxation (R-L-F subtype). Purple denotes fluid flow by impedance.

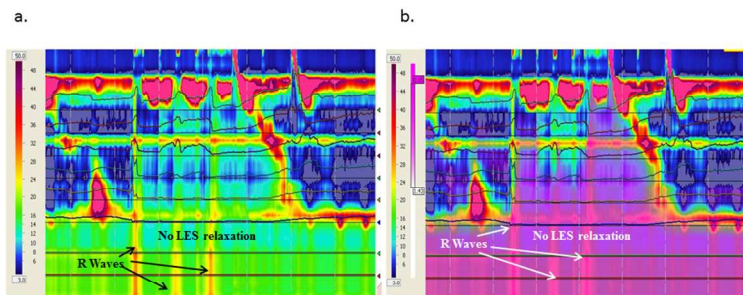


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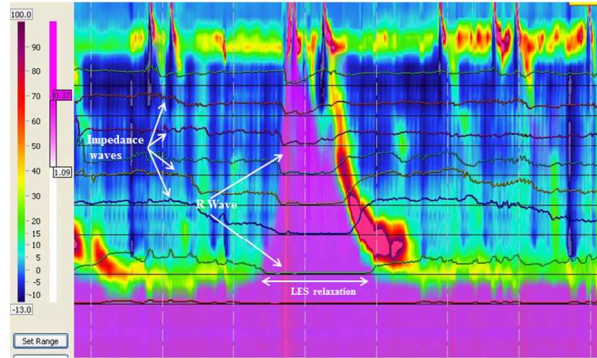
Figure 3. Primary rumination with R wave with no LES relaxation (N-R-F subtype). Purple denotes fluid flow by impedance. The figures represent the same rumination episodes without (a) and with (b) the purple impedance added to show bolus flow despite a closed LES.



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Figure 4. An example of secondary rumination. There is LES relaxation with retrograde flow before the R wave occurs.

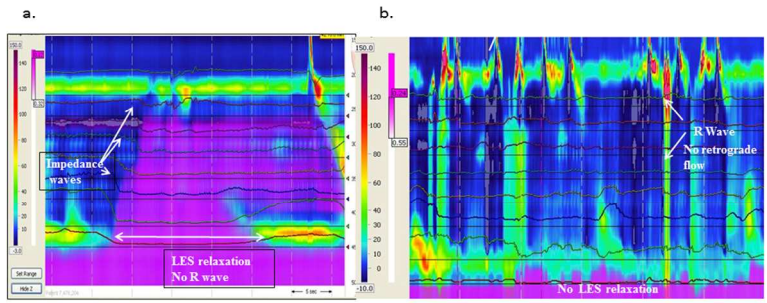


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Figure 5. Examples of episodes where HRM-MII disproved rumination including reflux episodes with a TLESR and retrograde bolus flow (a) and generation of R waves without bolus flow. Purple represents liquid by impedance.



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