J Clin Ultrasound 18:477–485, July/August 1990

Ultrasound Diagnosis of Gastroesophageal Reflux and Hiatal Hernia in Infants and Young Children

Sjirk J. Westra, MD,* Bart H. M. Wolf, MD,† and Chris R. Staalman, MD*

Abstract: In 30 young children suspected of gastroesophageal reflux (GER), the G–E junction was examined with ultrasonography directly after a feeding while these children were on overnight extended esophageal pH monitoring (EEpHM) (32 simultaneous ultrasound/EEpHM studies). The two tests showed 81% to 84% agreement in the detection of the presence or absence of GER, depending on whether the whole period of EEpHM or only the part of it covering the ultrasound observation period were used as the standard. The discrepancies between the two tests were explained by the much longer monitoring period of EEpHM compared to ultrasonography and the inability of EEpHM to show reflux of neutralized gastric contents directly after milk feedings. The two studies probably measure different aspects of clinically significant reflux and must be correlated with the clinical symptoms. Morphological findings associated with significant reflux were (1) a short intra-abdominal part of the esophagus, (2) a rounded gastroesophageal angle, and (3) a "beak" at the gastroesophageal junction. Barium meal findings confirmed these sonographic signs, indicating a sliding hiatal hernia of the distal esophagus, either fixed or intermittent. Ultrasonography can be recommended as a useful and physiological screening test to demonstrate clinically significant GER and a predisposing hiatal hernia of the esophagus in symptomatic children. **Indexing Words:** Children, gastrointestinal tract · Esophagus, reflux · Stomach, reflux · Hernia, hiatal · Gastrointestinal tract, ultrasound studies

Gastroesophageal reflux (GER) is a common disorder in infants and children. In the great majority it constitutes a "physiological" event and is of little clinical significance.[1,2] However, this often apparently benign and self-limiting disorder is now increasingly being recognized as a cause of failure to thrive, extreme irritability, unusual posturing, esophagitis, chronic blood loss, esophageal stricture, recurrent pneumonia, reactive airway disease, and possibly apnea of infancy even in the absence of overt emesis.[3,4]

Considerable confusion exists over what constitutes significant GER and how best to diagnose it. The barium upper gastrointestinal study (UGS) is a time-honored, first-line diagnostic test to demonstrate both reflux and structural anomalies (hiatal hernia)[5] or functional disorders (delayed gastric emptying: "antral dyskinesia")[6,7] that may predispose to regurgitation. It can also show complications of GER like esophagitis, peptic stenosis, and aspiration into the bronchial tree. This test is widely available, noninvasive, and comparatively cheap. However, acceptable fluoroscopy time prohibits the detection of GER occurring infrequently or only under certain circumstances (e.g., at night, in the upright position, in the fasting state). Indeed, the sensitivity of the UGS has been shown to be less than tests that monitor GER over a prolonged period [acid reflux (Tuttle) test, extended esophageal pH monitoring (EEpHM), and reflux scintigraphy].[1,8–18] Because early postprandial reflux on EEpHM was found to be a common event in asymptomatic children[4,19–21] and the UGS some-

From the Departments of *Diagnostic Radiology and the †Pediatrics, University of Amsterdam, Academisch Medisch Centrum, Amsterdam, The Netherlands. For reprints contact Sjirk J. Westra, MD, Department of Radiological Sciences, UCLA Medical Center, 10833 Le Conte Ave., Los Angeles, CA 90024-1721.

CCC 0091-2751/90/060477-09 $04.00

times employs nonphysiological methods in order to provoke GER,[4] the specificity of the UGS has been questioned also.[14–16] The high incidence of false positive and false negative results of the UGS make this test less valuable for confirming the diagnosis of GER.[16,22]

There are few published data on the use of ultrasonography to demonstrate GER.[23,24] These have shown ultrasonography to be more sensitive than the UGS as its lack of ionizing radiation allows for a longer observation period for evaluating the G–E junction. In order to determine the value of this new modality in the diagnosis of GER, we performed ultrasound examinations simultaneously with pH recording in symptomatic children who were evaluated for GER with overnight EEpHM. In addition, the morphology of the G–E junction was studied using high-resolution ultrasound images and compared with the UGS findings in all these children.

METHODS

Population

During a period of one year, all 30 children in whom overnight EEpHM studies were performed for symptoms suspected to result from GER were included in this study. Vomiting or regurgitation were noted in 13 patients, failure to thrive in 3, apneic and/or cyanotic spells in 8, intermittent torticollis in 1, excessive crying in 2, retrosternal pain in 1, recurrent respiratory infections in 10, attacks of wheezing in 3, and chronic cough in 2 patients. There were 20 boys and 10 girls, ages 27 days to 9.5 years (median age 10 months). Two children were examined twice during the study period, resulting in 32 combined ultrasound/EEpHM studies. In 12/32 studies pathological GER had already been suspected or demonstrated on previous UGS or EEpHM, and these children came for confirmation and follow-up, respectively.

Extended Esophageal pH Recording

All medications were discontinued during the study period. A small flexible antimony electrode (Synectics medical 0011) calibrated with buffers at pH values of 1 and 7 was introduced transnasally, and its location 2 cm above the G–E junction was checked with fluoroscopy. A reference electrode was attached securely to the abdominal wall. Both electrodes were connected to a portable recording device (Digitrapper, Synectics AB,

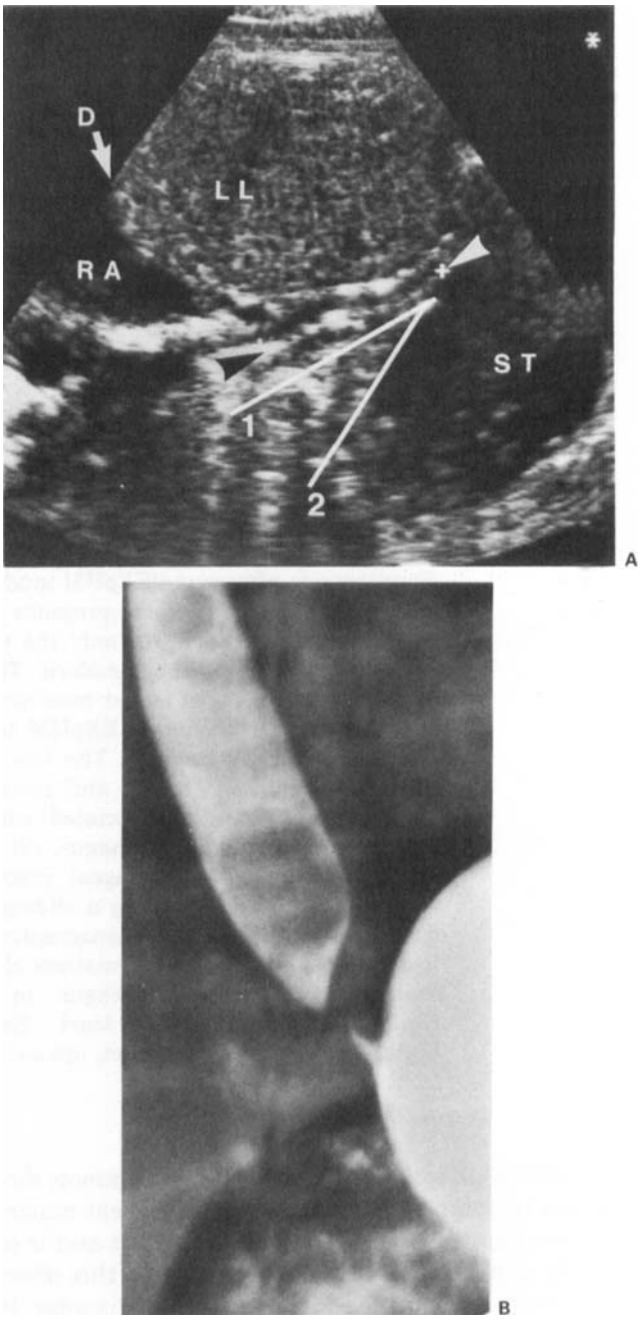


FIGURE 1. Gastroesophageal junction, normal anatomy. **(A)** Longitudinal section through intra-abdominal part of esophagus, the length of which (EL) is measured between the gastroesophageal junction (white arrowhead) and the place where the distal esophagus penetrates the diaphragm (diaphragmatic hiatus, black arrowhead), EL = 2.3 cm. Sharp gastroesophageal angle (GEA) of His, indicated by the angle between a line paralleling the most distal part of the esophagus (1) and a line tangent to the distended gastric fundus at the GE-junction (2). **(B)** Barium esophagogram, same patient: sharp GEA. (Key to Figures 1 to 4: A, aorta; D, diaphragm; H, hiatal hernia; IVC, inferior vena cava; LL, left lobe of liver; LC, left crus of diaphragm; RA, right atrium; RL, right lobe of liver; ST, fluid-filled lumen of stomach.)

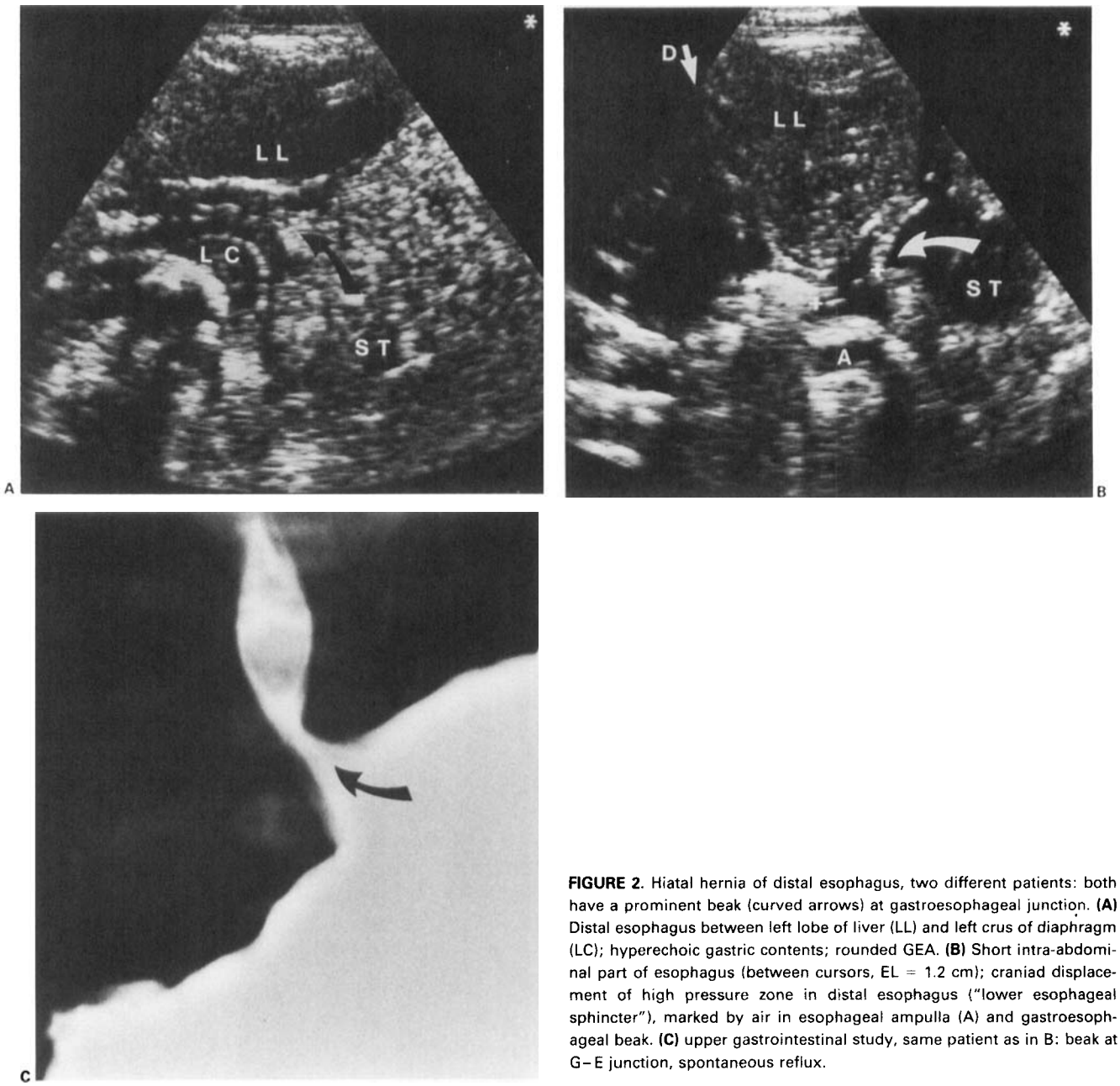
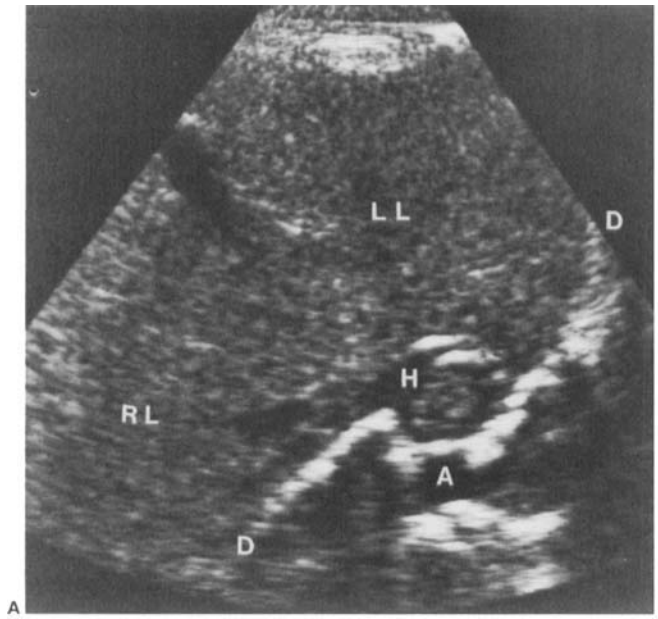
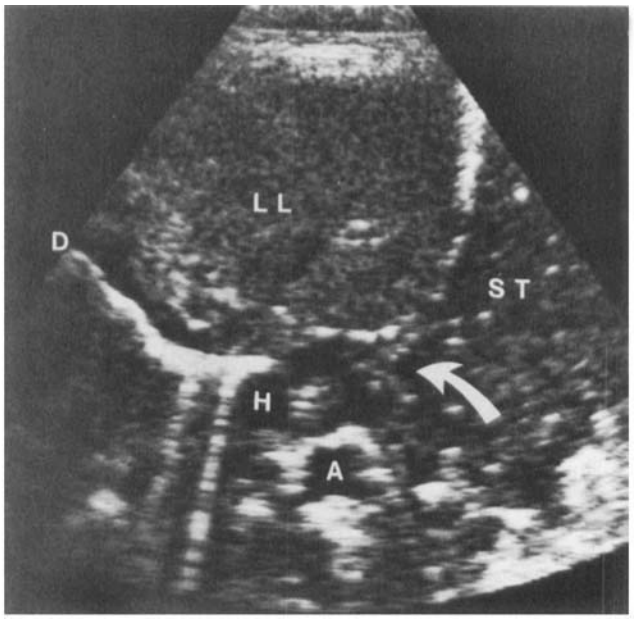


FIGURE 2. Hiatal hernia of distal esophagus, two different patients: both have a prominent beak (curved arrows) at gastroesophageal junction. **(A)** Distal esophagus between left lobe of liver (LL) and left crus of diaphragm (LC); hyperechoic gastric contents; rounded GEA. **(B)** Short intra-abdominal part of esophagus (between cursors, EL = 1.2 cm); craniad displacement of high pressure zone in distal esophagus ("lower esophageal sphincter"), marked by air in esophageal ampulla (A) and gastroesophageal beak. **(C)** upper gastrointestinal study, same patient as in B: beak at G–E junction, spontaneous reflux.

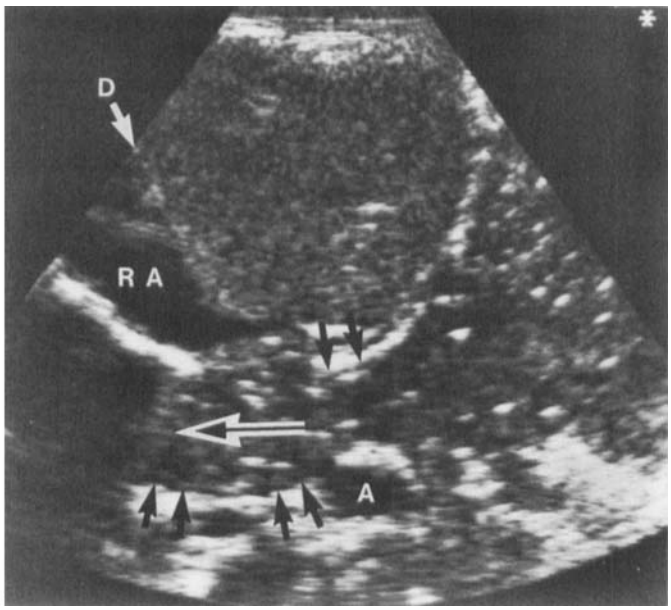
Stockholm). All children were hospitalized for 24 hours and pH recordings were made continuous for a period of at least 20 hours starting in the morning. The children were fed normally according to their age and habits at home. Those younger than 4 months were monitored in the prone position. Older babies and children were free to choose their position while asleep. Acid reflux was defined as esophageal pH < 4 and alcaline reflux was ignored in this study. All data were read using an Tulip computer and the software program "Ambulatory pH IBM" (Synectics AB, Stockholm). The following four variables for acid reflux were calculated for a 24-hour period: number of reflux episodes, number of reflux episodes lasting longer than 5 minutes, duration of longest reflux episode recorded, and reflux index (calculated as the percentage of the total investigation time when the pH was less than 4). A pH recording was considered abnormal if the value of any one of these parameters exceeded the appropriate age-specific normal range of values (mean + 2 SD), determined in asymptomatic children aged 0 months to 15 months.[19] Since normal values reported for the adult population[25] approach the normal ranges for infants aged 15 months,[19] we used these values for older children also.



A

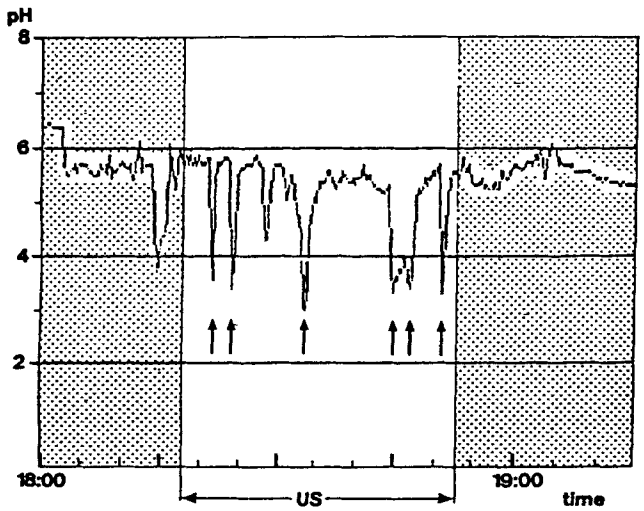


B



C

D



E

FIGURE 3. Fixed hiatal hernia of distal esophagus with pathological reflux. **(A)** Transverse section through high upper abdomen showing large "hernia" (H), penetrating the diaphragm (D). **(B)** Longitudinal section through intra-abdominal part of esophagus: "hernia" (H) in diaphragmatic hiatus, beak at gastroesophageal junction (curved arrow). **(C)** same sectioning plane: massive reflux (large arrow) with ballooning of distal esophagus (small arrows). **(D)** Upper GE study, water siphon test: massive reflux (also frequent spontaneous reflux was noted). **(E)** Continuous pH recording during ultrasound study: reflux episodes seen with ultrasonography were found to coincide with pH dips below 4 (arrows).

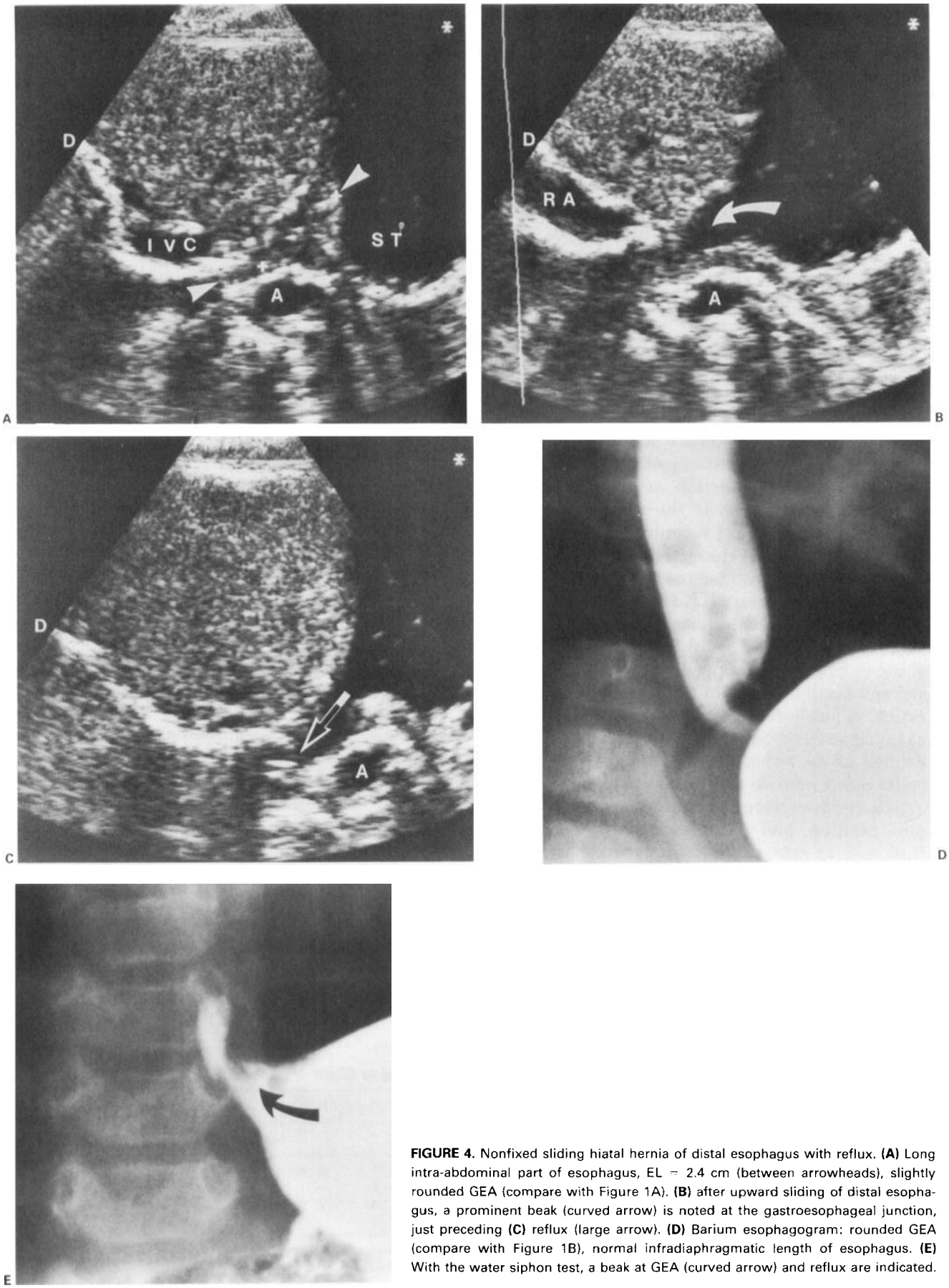


FIGURE 4. Nonfixed sliding hiatal hernia of distal esophagus with reflux. **(A)** Long intra-abdominal part of esophagus, EL = 2.4 cm (between arrowheads), slightly rounded GEA (compare with Figure 1A). **(B)** after upward sliding of distal esophagus, a prominent beak (curved arrow) is noted at the gastroesophageal junction, just preceding **(C)** reflux (large arrow). **(D)** Barium esophagogram: rounded GEA (compare with Figure 1B), normal infradiaphragmatic length of esophagus. **(E)** With the water siphon test, a beak at GEA (curved arrow) and reflux are indicated.

Ultrasonography

The ultrasound examinations were performed 6 hours to 8 hours after introduction of the pH probe, as soon as possible after a meal consisting of formula in young infants, whereas in older children only drinks and semisolids like porridge or custard were allowed. Preceding the ultrasound study, young infants were "burped" in their usual fashion. A high-resolution 5-mHz sector transducer (Diasonics, Milpitas, CA, or Acuson, Mountain View, CA) was placed in the midline under the xiphisternum and the distal esophagus was identified at the location where it penetrated the diaphragm on transverse sections. The transducer was then rotated and repositioned to obtain a longitudinal section through the intra-abdominal part of the distal esophagus. This structure was observed for 20 minutes and the whole study was recorded on videotape. Still-frame images of the anatomy of the distal esophagus and the G–E junction were obtained. The beginning and the end of the ultrasound study were marked on the pH recording.

A reflux episode is characterized by the following sequence of events: opening of the lower esophageal sphincter (LES), gastric contents moving up the distal esophagus, to-and-fro movement of these in the distal esophagus, clearance of the esophagus of refluxed material by peristalsis, and finally closing of the LES. The total duration of each reflux episode including esophageal clearance was noted. A negative result was defined as no reflux or only one short (<2 seconds) reflux episode per 20 minutes.

The children were examined mainly in the supine position, and apart from rolling the child from side to side, no reflux provoking measures were applied. A pacifier was allowed if this made a child more comfortable; this did not lead to an increase of the amount of reflux observed. The following observations regarding the anatomy of the G–E junction were recorded (Figures 1–4): the length of the intra-abdominal part of the esophagus (EL), the angle which the distal esophagus was seen to meet with the stomach wall [gastroesophageal angle (GEA), sharp or rounded], and the presence or absence of a "beak" at the G–E junction. All ultrasound studies were carried out by one examiner (SJW). At the time of the ultrasound study, the pH meter readings were not visible, and no clinical information or results of previous examinations were available to the examiner.

The Barium Upper Gastrointestinal Study

This was carried out in all children using a standardized approach described previously,[26] with the inclusion of the water siphon test.[8] No other reflux-provoking measures were applied. Presence or absence of a hiatal hernia and/or a beak at the G–E junction were noted.

RESULTS

On EEpHM, 20 studies demonstrated pathological GER and in 12 studies the reflux recorded was regarded as insignificant. Ultrasonography was positive for reflux in 19 out of the 20 studies showing reflux with EEpHM (Table 1). Sonographic indications of reflux coincided with the pH dips seen in the parts of the EEpHM printouts that covered the ultrasound observation period (Figure 3E) in 17 studies, whereas in two studies reflux seen with ultrasonography did not result in a simultaneous change of the esophageal pH. In the child with pathological reflux on EEpHM in whom no reflux was seen with ultrasonography, no pH changes were noted during the ultrasound observation period and all reflux recorded by the pH probe occurred in the upright position.

Of the 12 EEpHM-negative studies, ultrasonography was negative for reflux in 7 and positive in 5 (Table 1). In 2 of the latter, this reflux coincided with pH dips occurring almost exclu-

TABLE 1
Ultrasound Evaluation Compared to EEpM

	EEpM (Overall Result)					
	Positive			Negative		
Ultrasonography: positive	19	pH change[a]: Pos	17	5	pH change[a]: Pos	2
		Neg	2		Neg	3
Ultrasonography: negative	1	pH change[a]: Pos	0	7	pH change[a]: Pos	0
		Neg	1		Neg	7

[a]pH change pos: reflux episode(s) seen with ultrasonography always followed by drop in pH.
pH change neg: no ph change recorded during ultrasound examination period.

sively during the ultrasound observation period, whereas the overall result of the EEpHM turned out to be negative. In the remaining 3 studies, no pH changes during the reflux episodes seen with ultrasonography were recorded.

Based on length measurements of the intra-abdominal part of the distal EL and observations of G–E junction anatomy, the whole study group was divided into three subgroups:

1. EL ≥ 2 cm, GEA sharp, no beak at the G–E junction (6 studies, Figure 1). In none of these cases was reflux seen with ultrasonography. UGS revealed normal G–E junction anatomy in all.
2. EL < 2 cm, GEA rounded, beak at the G–E junction (11 studies, Figures 2 and 3). UGS showed these findings to represent a fixed hiatal hernia of the intra-abdominal part of the esophagus (actual herniation of part of the stomach was never encountered). In all 11 studies where these signs were seen, ultrasonography showed gross reflux.
3. The signs mentioned under 1 and 2 were seen to alternate during the study period (15 studies; Figure 4). With UGS, a beak at the G–E junction was demonstrated, often only during the water siphon test (Figure 4D,E). In 12 of the 15 studies where these criteria applied, reflux was seen with ultrasonography only while the "hernia" was present, and in some the distal esophagus was seen to actually slide up through diaphragmatic hiatus just before reflux occurred. In three studies, despite intermittent upward sliding of the distal esophagus, no reflux was seen.

DISCUSSION

In the young thriving infant with typical postprandial regurgitation, the diagnosis of reflux can be made on the basis of the clinical history alone. In pediatric patients with more severe gastrointestinal or respiratory symptoms, a more thorough documentation of GER is often requested.[4] The difficulty in defining what is pathological reflux in the various age groups has led to a proliferation of tests aimed to objectively detect and quantify reflux over longer periods of time. Although a reliable "gold standard" to assess the clinical significance of GER is not available at present, EEpHM is proposed as the best technique available.[27–32] The relative invasiveness of this test, the need for hospitalization and the equipment needed precludes it being employed as a screening test in symptomatic children.

With ultrasonography, the anatomy and pathophysiology of the G–E junction can be studied and the mechanisms known to prevent reflux[33,34] can be examined in detail: (1) the competency of the LES, depending mainly on its intra-abdominal location; (2) the length of the intra-abdominal part of the esophagus and the angle of His, resulting in a check-valve mechanism when the gastric fundus is distended; and (3) the ability of the diaphragmatic crura to hold the distal esophagus in place in the esophageal hiatus, preventing it from sliding upward. We have described the ultrasound signs of a sliding hiatal hernia of the distal esophagus, either fixed or nonfixed, and we showed that this condition predisposed to significant reflux. Most forms of antireflux surgery attempt to increase the intra-abdominal length of the eosphagus, thereby restoring the normal antireflux mechanism.[34] Ultrasonography is the only noninvasive technique by which this important parameter can be evaluated directly.

Using the full overnight EEpHM period as the standard, ultrasonography showed a "sensitivity" for GER of 95% and a "specificity" of 58%. In the single study positive for reflux on EEpHM but negative on ultrasonography the absence of reflux during the ultrasound observation period was confirmed by EEpHM, which recorded reflux only in the upright position. In 2 of the 5 studies negative for reflux on EEpHM but positive on ultrasonography, the reflux seen with ultrasonography was also demonstrated on the part of the pH recording covering the ultrasound observation period. The discrepancies between the two tests can be explained by the much longer observation period for EEpHM compared to ultrasonography. In 3/12 studies negative for reflux and 2/20 studies positive for reflux on EEpHM, no pH changes were recorded following reflux seen with ultrasonography. In EEpHM, postprandial reflux may not be detected if the gastric contents are not acid, as is often the case directly after feeding, leading to an underestimation of the amount of reflux.[35] In addition, controversy exists about the significance of postprandial reflux, and some authors consider reflux occurring within 2 hours of feeding to be physiological[19–21,28,31,32,36] and ignore this reflux in the interpretation of the recordings. In contrast, ultrasonography (and the UGS) makes use of a full stomach in order to "provoke" reflux and therefore detects postprandial reflux.

In a significant number of studies, immediately after reflux was seen with ultrasonography, symptoms like vomiting, wheezing, coughing, apnea, hyperactivity, crying, intermittent

opisthotonus, and torticollis were noted, often the very same symptoms that prompted the parents to seek medical advice. Therefore we felt that despite a pH recording considered to be within normal limits for age, such "symptomatic" reflux shown by ultrasonography did have pathological significance. Using EEpHM, proving such a relationship between reflux and symptoms is much more difficult, and requires the employment of sophisticated polygraphic equipment.[4,37-39] We believe imaging tests like UGS and ultrasonography, and functional tests like EEpHM, measure different aspects of clinically significant GER, and are confirmatory and complementary rather than competitive.[40] Whereas some authors perform as many as 5 different tests for reflux and require 3 of these to be positive before a diagnosis of pathological reflux is made,[22] others state that a suggestive history and a positive UGS only constitute adequate evidence of reflux for the institution of medical therapy.[1] As long as a reliable "gold standard" for the assessment of clinically significant reflux is lacking,[22] the terms "sensitivity" and "specificity" are less suitable in characterizing a new test like ultrasonography.

In conclusion, we found ultrasonography a useful test for demonstrating clinically significant reflux. A causal relationship between reflux and ensuing symptoms can be suspected. A sliding hiatal hernia of the distal esophagus, leading to LES incompetency, can be identified. We are currently evaluating a larger population of symptomatic and asymptomatic children for presence or absence of symptoms following observed reflux and signs of an associated hiatal hernia. This study is designed to test our hypothesis that such reflux must be considered pathological, thereby improving the specificity of ultrasonography. Because ultrasonography is a relatively inexpensive, noninvasive, physiological, and widely available test not employing ionizing radiation, it can be recommended as a first-line screening test in symptomatic children. A history strongly suggestive of GER combined with positive ultrasound findings justify a therapeutic trial with conservative antireflux measures. EEpHM and esophagoscopy with biopsy can be reserved as confirmatory tests if required, especially in therapy-resistant patients in whom surgery is considered. If the clinical history and/or ultrasound findings point to a gastric outlet obstruction other than hypertrophic pyloric stenosis as the cause of reflux, a UGS should always be performed in order to exclude a malrotation or duodenal web, as these conditions may require urgent surgical intervention.

ACKNOWLEDGMENTS

The authors thank Hans Sibum for photographical assistance and Henk W. Venema, PhD, for his helpful comments in reviewing the manuscript.

REFERENCES

1. Herbst JJ: Gastroesophageal reflux. *J Pediatr* 98:859–870, 1981.
2. Carre IJ: Management of gastro-esophageal reflux. *Arch Dis Child* 60:71–75, 1985.
3. Malfroot A, Vandenplas Y, Verlinden M, et al: Gastroesophageal reflux and unexplained chronic respiratory disease in infants and children. *Pediatr Pulmonol* 3:208–213, 1987.
4. Sondheimer JM: Gastroesophageal reflux: Update on pathogenesis and diagnosis. *Ped Clin North Am* 35:103–116, 1988.
5. Darling DB: Hiatal hernia and gastroesophageal reflux in infancy and childhood: Analysis of the radiologic findings. *AJR* 123:724–736, 1975.
6. Hillemeier AC, Lange R, McCallum R, Seashore J, Grybosky J: Delayed gastric emptying in infants with gastroesophageal reflux. *J Pediatr* 98:190–193, 1981.
7. Byrne WJ, Kangarloo H, Ament ME, et al: Antral dysmotility, an unrecognized cause of chronic vomiting during infancy. *Ann Surg* 193:521–524, 1981.
8. Blumhagen JD, Christie DL: Gastroesophageal reflux in children: Evaluation of the water siphon test. *Radiology* 131:345–349, 1979.
9. Heyman S, Kirkpatrick JA, Winter HS, Treves S: An improved radionuclide method for the diagnosis of gastroesophageal reflux and aspiration in children (milk scan). *Radiology* 131:479–482, 1979.
10. Rudd TG, Christie DL: Demonstration of gastroesophageal reflux in children by radionuclide gastroesophagography. *Radiology* 131:483–486, 1979.
11. Arasu TS, Wyllie R, Fitzgerald JF, et al: Gastroesophageal reflux in infants and children: Comparative accuracy of diagnostic methods. *J Pediatr* 96:798–803, 1980.
12. Blumhagen JD, Rudd TG, Christie DL: Gastroesophageal reflux in children: Radionuclide gastroesophagography. *AJR* 135:1001–1004, 1980.
13. Euler AR, Byrne WJ: Twenty-four-hour esophageal intraluminal pH probe testing: A comparative analysis. *Gastroenterology* 80:957–961, 1981.
14. Seibert JJ, Byrne WJ, Euler AR, Latture T, Leach M, Campbell M: Gastroesophageal reflux—The

acid test: Scintigraphy or the pH probe? *AJR* 140:1087–1090, 1983.
15. Cleveland RH, Kusher DC, Schwartz AN: Gastroesophageal reflux in children: Results of a standardized fluoroscopic approach. *AJR* 141:53–56, 1983.
16. Leonidas JC: Gastroesophageal reflux in infants: Role of the upper gastrointestinal series [editorial]. *AJR* 143:1350–1351, 1984.
17. González Fernández F, Argüelles Martin F, Rodriguez de Quesada B, González Hachero J, Valls Sánchez de Puerta A, Gentles M: Gastroesophageal scintigraphy: A useful screening test for GE reflux. *J Pediatr Gastroenterol Nutr* 6:217–219, 1987.
18. Bowen A: The vomiting infant: Recent advances and unsettled issues in imaging. *Radiol Clin North Am* 26:377–392, 1988.
19. Vandenplas Y, Sacré-Smits L: Continuous 24-hour esophageal pH monitoring in 285 asymptomatic infants 0-15 months old. *J Pediatr Gastroenterol Nutr* 6:220–224, 1987.
20. Vandenplas Y, De Wolf D, Deneyer M, Sacre L: Incidence of gastroesophageal reflux in sleep, awake, fasted, and postcibal periods in asymptomatic and symptomatic infants. *J Pediatr Gastroenterol Nutr* 7:177–180, 1988.
21. Sutphen JL, Dillard VL: Effect of feeding volume on early postcibal gastroesophageal reflux in infants. *J Pediatr Gastroenterol Nutr* 7:185–188, 1988.
22. Meyers WF, Roberts CC, Johnson DG, Herbst JJ: Value of tests for evaluation of gastroesophageal reflux in children. *J Pediatr Surg* 20:515–520, 1985.
23. Naik DR, Moore DJ: Ultrasound diagnosis of gastro-oesophageal reflux. *Arch Dis Child* 59:366–379, 1984.
24. Naik DR, Bolia A, Moore DJ: Comparison of barium swallow and ultrasound in diagnosis of gastro-oesophageal reflux in children. *Br Med J* 290:1943–1945, 1985.
25. Johnson LF, DeMeester TF: Twenty-four hour pH monitoring of the distal esophagus: A quantitative measure of gastroesophageal reflux. *Am J Gastroenterol* 62:325–332, 1974.
26. McCauley RGK, Darling DB, Leonidas JC, Schwartz AM: Gastroesophageal reflux in infants and children: A useful classification and reliable physiologic technique for its demonstration. *AJR* 130:47–50, 1978.
27. Hill JL, Pelligrini CA, Burrington JD, Reyes HM, DeMeester TR: Technique and experience with 24-hour esophageal pH monitoring in children. *J Pediatr Surg* 12:877–887, 1977.
28. Jolley SG, Herbst JJ, Johnson DG, Book LS, Matlak ME, Condon VR: Patterns of postcibal gastroesophageal reflux in symptomatic infants. *Am J Surg* 138:946–950, 1979.
29. Boix-Ochoa J, Lafuente JM, Gil-Vernet JM: Twenty-four hour esophageal pH monitoring in gastroesophageal reflux. *J Pediatr Surg* 15:74–78, 1980.
30. Koch A, Gass R: Continuous 20-24 hr esophageal pH-monitoring in infancy. *J Pediatr Surg* 16:109–113, 1981.
31. Johnson DG, Jolley SG, Herbst JJ, Cordell LJ: Surgical selection of infants with gastroesophageal reflux. *J pediatr Surg* 16:587–594, 1981.
32. Jolley SG, Johnson DG, Herbst JJ, Matlak ME: The significance of gastroesophageal reflux patterns in children. *J Pediatr Surg* 16:859–865, 1981.
33. Herbst JJ, Book LS, Johnson DG, Jolley S: The lower esophageal sphincter in gastroesophageal reflux in children. *J Clin Gastroenterol* 1:119–123, 1979.
34. Boix-Ochoa J. Address of honoured guest: The physiologic approach to the management of gastric esophageal reflux. *J Pediatr Surg* 21:1032–1039, 1986.
35. Sutphen JL, Dillard VL: Effects of maturation and gastric acidity on gastroesophageal reflux in infants. *Am J Dis Child* 140:1062–1064, 1986.
36. Jolley SG, Herbst JJ, Johnson DG, Matlak ME, Book LS: Esophageal pH monitoring during sleep identifies children with respiratory symptoms from gastroesophageal reflux. *Gastroenterology* 80:1501–1506, 1981.
37. Herbst JJ, Minton SD, Book LS: Gastroesophageal reflux causing respiratory distress and apnea in newborn infants. *J Pediatr* 95:763–768, 1979.
38. Ariagno RL, Guilleminault C, Baldwin R, Owen-Boeddiker M: Movement and gastroesophageal reflux in awake term infants with "near miss" SIDS, unrelated to apnea. *J Pediatr* 100:894–897, 1982.
39. Menon AP, Schefft GL, Thạch BT: Apnea associated with regurgitation in infants. *J Pediatr* 106:625–629, 1985.
40. Blane CE, Klein MD, Drongowski RA, Sarahan TM, Wesley JR, Coran AG: Gastroesophageal reflux in children: Is there a place for the upper gastrointestinal study? *Gastrointest Radiol* 11:346–348, 1986.