

Hypertrophic Pyloric Stenosis: Use of the Pyloric Volume Measurement in Early US Diagnosis¹

The diagnosis of hypertrophic pyloric stenosis (HPS) with ultrasonography (US) is dependent on measurements of pyloric diameter (PD), pyloric length (PL), and muscle thickness. The authors were unable to confidently diagnose the condition with US in 45% of patients who underwent surgery for HPS because all three criteria were not fulfilled. An overall measurement of the "amount" of pyloric hypertrophy was introduced: pyloric volume (PV), which was equated to $\frac{1}{4}\pi \times PD^2 \times PL$. No overlap was found between patients with HPS ($n = 22$; $PV = 3.13$ mL; range, 1.4–5.1 mL) and asymptomatic control subjects ($n = 28$; $PV = 0.65$ mL; range, 0.2–1.3 mL) or symptomatic subjects without HPS ($n = 25$; $PV = 0.86$ mL; range, 0.4–1.3 mL). A positive correlation was found between age at diagnosis and PV, a finding reflecting that HPS is an acquired condition. In patients less than 4 weeks of age, the criterion of PV greater than or equal to 1.4 mL proved to aid in the identification of early HPS more accurately than any existing criteria.

Index terms: Pylorus, stenosis, 724.1431 • Pylorus, US studies, 724.12981 • Ultrasound (US), in infants and children

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See also the editorial by Carroll (605–608) in this issue.

IN the years after the introduction of ultrasonography (US) as an aid in the diagnosis of hypertrophic pyloric stenosis (HPS) (1), criteria have been established for measurements of the pyloric muscle in the normal and hypertrophied state (2–20). Because considerable overlap was found between healthy subjects and patients with HPS in measurements of pyloric diameter (PD) (6,9,10–14,17,19), muscle thickness (MT) (4,6,10–14,17,19), and pyloric length (PL) (13,17–19), controversy still exists about the criteria to be employed for the reliable US diagnosis or exclusion of HPS in infants with a history of vomiting (20). Whatever criteria are chosen, the diagnostic procedure to be followed is not clear when all three criteria are not fulfilled.

Because HPS is regarded by most authors (21,22) to be an acquired rather than a congenital condition, a "gray area" between normality and HPS is to be expected. In infants with a short duration of symptoms in whom no "olive" can be felt, US is expected to play an important role in the medical decision process (20). Conversely, in more advanced cases with a larger, palpable pyloric muscle, imaging will not be required for diagnosis.

The purpose of this study was to prospectively reevaluate the reliability of the previously mentioned diagnostic US criteria, especially in the younger age groups, and to determine the value of an overall measurement of pyloric hypertrophy that is derived from PD and PL values: pyloric volume (PV).

PATIENTS AND METHODS

From September 1986 to August 1988, 47 infants with a history of vomiting who were suspected to have HPS were referred to the US department. There were 33 boys and 14 girls, aged 7 days to 18 weeks. A group of 28 infants hospitalized for unrelated conditions constituted the

control population (neonatal abstinence syndrome, $n = 8$; low birth weight/prematurity, $n = 7$; cardiac malformations, $n = 4$; seizures or hypotonia, $n = 4$; pneumonia, $n = 1$; vitamin K deficiency, $n = 1$; congenital hypothyroidism, $n = 1$; acute tubular necrosis, $n = 1$; postnatal asphyxia, $n = 1$; and cephalhematoma, $n = 1$). This control group included 18 boys and 10 girls, aged 9 days to 16 weeks.

US was performed with a real-time scanner equipped with a 5-MHz transducer (Diasonics, Milpitas, Calif; Acuson, Mountain View, Calif). Because distention of the pyloric antrum with a clear fluid facilitates US imaging of the pylorus, all symptomatic infants were first screened in the supine position to determine the amount of gastric retention. To improve imaging of the pylorus, if necessary, the patients were bottle-fed and then examined. All control subjects were examined immediately after a usual feeding. The pylorus was imaged most often with the child in the right decubitus position. Longitudinal and transverse sections were obtained through the antropylic region, and this area was observed for approximately 10 minutes for signs of pyloric relaxation and passage of gastric contents.

The pyloric muscle was measured for diameter, thickness, and length (Fig 1a, 1c). Throughout the study, the criteria for HPS formulated by Tunell and Wilson (10) were employed ($PD \geq 1.3$ cm, $MT \geq 0.4$ cm, $PL \geq 1.9$ cm). With these criteria, the study population was divided into three groups: definite HPS (all three criteria were fulfilled [Fig 1b, 1c]), HPS not supported (none of the criteria were met [Fig 2]), and indeterminate findings (Fig 3). For reproducibility, PD was only determined with the muscle closed (Fig 2a). In patients in whom the muscle was not seen to close during the observation period, the lumen diameter was subtracted from the measured value of PD with the muscle open. In addition to the three criteria already mentioned, we introduced PV as a new criterion. With the volume of

Abbreviations: HPS = hypertrophic pyloric stenosis, MT = muscle thickness, PD = pyloric diameter, PL = pyloric length, PV = pyloric volume.



Figure 1. (a) Schematic representation of the pyloric muscle as a cylinder with radius $PD/2$ and height PL . (b, c) Longitudinal US scans through large pyloric muscle mass show HPS. (b) Prominent antral beak, pyloric shoulder, and double-track signs are present. (c) $PD = 1.7$ cm (between open arrows), $PL = 2.1$ cm (between curved arrows), calculated $PV = 4.8$ mL.

a cylinder with radius r and height h being equal to $\pi \times r^2 \times h = \frac{1}{4}\pi \times (2r)^2 \times h$, we defined PV on the basis of the formula $PV = \frac{1}{4}\pi \times (PD)^2 \times PL$ (Fig 1a). For all measurements studied, the mean values and standard deviations in the three study groups were calculated, and differences were checked for statistical significance with a two-sided Student t test.

RESULTS

Table 1 and Figure 4 summarize the results of pyloric measurements in the group of 47 vomiting infants, compared with those in the 28 control subjects. Twenty-two infants (two female and 20 male, aged 18–103 days) underwent surgery for HPS. In 12 of these 22 patients (55%), HPS had been confidently diagnosed with the aid of US (Fig 1b, 1c). However, in 10 infants with HPS, US findings were indeterminate because all three criteria were not met. Findings were positive in seven patients with only the PD and MT criteria, in two with only the MT criterion, and in one with only the PD criterion. In all 10 patients, the diagnosis was established with a barium study (Fig 3). Two illustrative case reports follow.

Case 1.—An 18-day-old infant boy presented with a history of projectile vomiting for 2 days. Because his father and brother had undergone surgery for pyloric stenosis, early medical advice was sought by the parents. US scans demonstrated gastric retention and some passage of air and fluid through a minimally elongated pyloric channel, with prolonged gastroesophageal reflux. Pyloric muscle measurements were considered indeterminate ($PL = 1.8$ cm, $PD = 1.0$ cm, $MT = 0.3$ – 0.4 cm, calculated $PV = 1.4$ mL). A barium study was therefore recommended and showed a double-

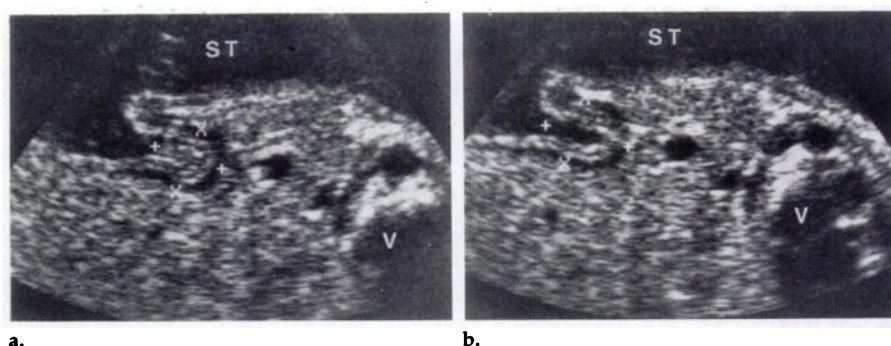


Figure 2. Transverse US scans through upper abdomen show normal pylorus. ST = fluid-filled stomach, V = vertebral body. (a) With pylorus closed, $PD = 1.1$ cm (between $\times$ s), $PL = 1.2$ cm (between $+$ s), calculated $PV = 1.14$ mL. (b) Pylorus is seen in open position for passage of gastric contents.

Table 1
Summary of Results of Pyloric Measurements in 75 Symptomatic and Asymptomatic Patients

Measurement	Control Subjects ($n = 28$)	Infants with Vomiting ($n = 47$)	
		Reflux ($n = 25$)	HPS ($n = 22$)
PD (cm)	0.82 ± 0.18 (0.5–1.2)	$0.90 \pm 0.13^*$ (0.7–1.3)	$1.40 \pm 0.17^\dagger$ (1.0–1.8)
PL (cm)	1.16 ± 0.20 (0.8–1.5)	$1.30 \pm 0.25^\ddagger$ (0.9–1.7)	$1.95 \pm 0.31^\ddagger$ (1.5–2.6)
MT (cm)	...	...	0.48 ± 0.13 (0.3–0.7)
PV (mL)	0.65 ± 0.31 (0.2–1.3)	$0.86 \pm 0.27^\S$ (0.4–1.3)	$3.13 \pm 1.01^\ddagger$ (1.4–5.1)

Note.—Numbers represent means $\pm$ the standard deviation. Numbers in parentheses are ranges.

* $P = .07$.

$^\dagger P < .001$.

$^\ddagger P = .03$.

$^\S P = .02$.

track sign and hyperperistalsis without passage; thus, the patient underwent immediate surgery for HPS. A small pyloric muscle mass was found, and pyloromyotomy was performed (perioperative measurements: $PL = 1.5$ cm, $PD = 1.2$ cm, $MT = 0.3$ – 0.4 cm, calculated $PV = 1.7$ mL).

Case 2.—A 26-day-old infant boy was admitted because of persistent vomiting since birth, recently in a projectile manner. A barium study at the age of 12 days had demonstrated delayed gastric emptying without signs of HPS. Because mild reflux was seen, the patient underwent an-

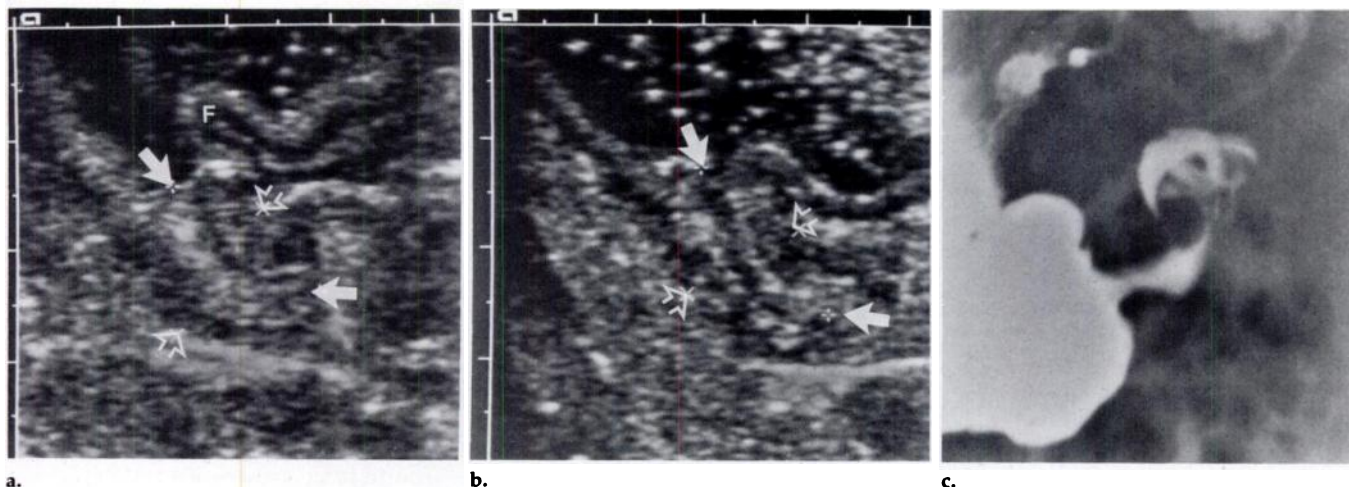
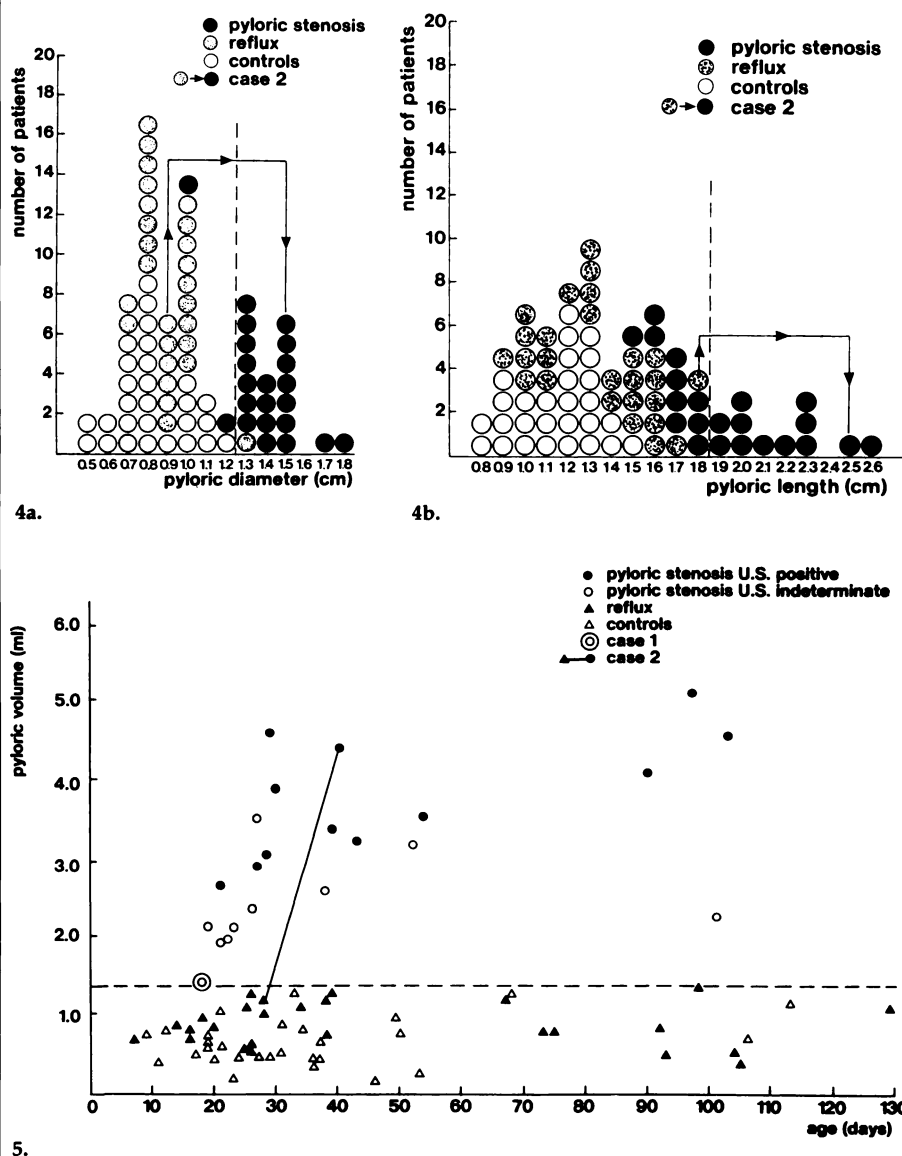


Figure 3. (a, b) Longitudinal US scans through pyloric muscle show indeterminate findings for HPS. (a) Scan obtained during peristaltic contraction of antropylic area shows prominent antral peristaltic fold (F); short, thick pyloric muscle; and curved pyloric channel. PD = 1.30 cm (between open arrows), PL = 1.65 cm (between closed arrows), calculated PV = 2.19 mL. (b) US scan obtained during antropylic relaxation shows long, thin pyloric muscle. PD = 1.15 cm (between open arrows), PL = 1.85 cm (between closed arrows), calculated PV = 1.92 mL. (c) Barium study in right anterior oblique position shows positive findings of HPS.



5.

Figures 4, 5. (4) Frequency distributions of measured PD (a) and PL (b). Dotted vertical lines = criteria of Tunell and Wilson (10). (5) PV plotted against age at US study.

tireflux therapy, without much success. At admission, US scans showed an elongated, thin pyloric muscle (PL = 1.8 cm, PD = 0.9 cm, calculated PV = 1.1 mL). Normal passage was observed and confirmed with a barium study, which again showed no signs of HPS. Antireflux measures were continued, and a regimen of small frequent feedings was instituted under clinical observation, with moderately successful results. During a 24-hour pH monitoring examination performed 2 weeks later, vomiting increased considerably and resulted in hypochloremic acidosis. At that time, the US findings were strongly positive (PL = 2.5 cm, PT = 1.5 cm, MT = 0.6 cm, calculated PV = 4.4 mL), and HPS was confirmed at surgery.

In the remaining 25 symptomatic infants, HPS was not supported with US findings. HPS was excluded with the help of a barium study in the 12 patients in whom this test was performed. US scans showed regular opening of the pyloric muscle with passage of gastric contents in all 25 patients (Fig 2). In all these infants with vomiting, gastroesophageal reflux was diagnosed on the basis of either barium studies ($n = 12$), 24-hour pH monitoring ($n = 7$), or clinical course and relief of symptoms with antireflux therapy ($n = 6$). Because these 25 patients improved with conservative treatment, no false-negative US results were encountered in this group. PV was calculated for all patients and control subjects (Table 1). Statistically significant differences ($P < .001$) between patients with and without HPS were found in mean

values of PD, PL, and PV. Overlapping values between patients with and without HPS were found in PD from 1.0 to 1.3 cm, PL from 1.5 to 1.7 cm, and MT of 0.3 cm (Table 1, Fig 4). In contrast, PV values in these groups did not overlap, and a complete separation at 1.4 mL was observed. Figure 5 shows PV as a function of age in all symptomatic patients and control subjects. In HPS, larger pyloric muscles were found with increasing age, whereas in patients with reflux and control subjects no such relationship existed.

DISCUSSION

Of all sonographic criteria for the diagnosis of HPS reported in the literature, measurements of PD and MT can be most easily performed with transverse sections through the hypertrophied muscle, which demonstrate the typical "target" or "cervix" sign in the right side of the upper abdomen (6). However, because a considerable overlap of 1.2–1.5 cm was found in PD measurements between healthy and control subjects, the value of this criterion was questioned (9,10). Our results showed that little overlap occurs when measurements are performed only on the closed muscle or are corrected for lumen diameter when the pylorus does not close during the examination. With this caveat, we found that PD, with a cutoff point of 1.3 cm, was a reliable criterion that can be determined accurately on both transverse and, preferably, longitudinal sections through the pyloric muscle. Only two patients with HPS had values for PD of less than 1.3 cm (Fig 4a).

Assessment of MT is hampered by the large measurement inaccuracy of 1 mm relative to the 3–4 mm criterion, on either side of which normal cases and cases of HPS are seen to cluster (10,11). In an asymmetrically hypertrophied muscle, as is often the case (Fig 1c), it is not clear where MT has to be measured. However, this easily performed and reproducible measurement allows normal cases to be separated from abnormal cases (18), as confirmed by our results. During real-time US screening, MT is simply evaluated and visually most directly related to the "amount of muscle hypertrophy" present.

Many transverse sections can be made through an elongated, hypertrophied pyloric muscle, but a true longitudinal section is more difficult to obtain. Measurements of length are therefore less reproducible. In

Table 2
Comparison of PV in HPS between Published Results and Current Study

Study	Pyloric Volume (mL)		Control Subjects
	HPS+	HPS–	
Graif et al (reference 11)	3.23 (1.7–4.9) [n = 17]	0.81 (0.3–1.2) [n = 5]	...
Cohen et al (reference 15)	3.14 (2.3–4.6) [n = 11]	...	...
Current study	3.13 (1.4–5.1) [n = 22]	0.86 (0.4–1.3) [n = 25]	0.65 (0.2–1.3) [n = 28]

Note.—HPS+ = infants with vomiting, HPS confirmed at surgery. HPS– = infants with vomiting, HPS excluded. Numbers represent means. Numbers in parentheses are ranges.

theory, only one such section is possible. In practice, the pyloric channel cannot always be imaged at full length in one sectioning plane because it is often curved (Figs 1b, 3a). Although PL is advocated as the most reliable criterion (10,11,13,14), this measurement is inherently less accurate for the reasons discussed previously. In addition, this criterion can be expected to fail in cases of short-segment pyloric stenosis (23). In our study, we used a cutoff point of 1.9 cm on the basis of the data of Tunell and Wilson (10); however, on the basis of more recent studies (13,14) and our results (Fig 4b), a value of 1.7 cm would be more appropriate for the separation of normal from abnormal cases. Still, a small overlap between the two groups was observed by most authors (13,17–19) and was also noted in our results. Although a lower length criterion of 1.7 cm would have reduced the number of indeterminate cases of HPS in our study from 10 to five without causing false-positive diagnoses, a complete separation between normal cases and cases of HPS could not be reached by means of any combination of the PD, MT, and PL measurements.

We found that PV was the most reliable overall measurement of muscle hypertrophy. Although mean values of PD, PL, and PV were all found to differ significantly ($P < .001$) between individuals with and without HPS, PV was the only criterion that showed no overlap between these groups. We were able to calculate PV from the data presented in two published series (12,15). The results of these calculations are similar to those obtained in our study (Table 2).

A seemingly more exact but complicated formula (pyloric muscle index) to calculate pyloric volume has been presented in an article by Carver et al (24). The results in this study are similar to those observed in ours. However, a correction for body weight was required to separate nor-

mal from abnormal cases, which we found to be unnecessary. Calculations in both the study by Carver et al and our study were based on the formula for the volume of a cylinder with flat ends, but the often curved and asymmetrically hypertrophied pyloric muscle is not exactly shaped that way (Figs 1b, 3a). Our approximation of PV appeared to be sufficiently reliable for practical use, and we question the need for the employment of more "exact" calculations because the aim is merely to separate normal from abnormal cases. In most cases of HPS, the measurements and calculations discussed in this article are superfluous, and the experienced sonographer can establish the diagnosis with inspection alone. In the relatively few doubtful cases that may remain, our formula for PV, which is simple and easy to memorize, might find wider acceptance than the pyloric muscle index discussed previously.

The age-dependency of PV in our cases of HPS (Fig 5) further supports the theory that HPS is an acquired rather than a congenital condition evolving within a short period of time from prolonged pylorospasm (21,22). Interestingly, slightly larger pyloric muscles were found in patients with reflux than in asymptomatic control subjects (mean PV = 0.86 and 0.65 mL, respectively; $P = .02$). Delayed gastric emptying due to pylorospasm is one of the factors known to contribute to gastroesophageal reflux (25,26). In the pathogenesis of HPS, an all-or-nothing mechanism seems to operate when the critical volume of 1.4 mL is reached. In our opinion, case 1—which demonstrates this borderline value in a young patient with a short history of vomiting—represents the earliest phase of pyloric hypertrophy. Case 2 illustrates the natural course of the disease with a transition of intermittent pylorospasm into complete HPS in less than 2 weeks, a time period in

which PV was seen to increase from 1.1 to 4.4 mL.

In borderline cases, we found pyloric dimensions to depend critically on the peristaltic contraction phase of the antropyloric area (Fig 3). During active peristalsis, the pyloric muscle appeared shorter, thicker, and more curved than during relaxation of the gastric outlet, factors resulting in the conflicting measurements obtained during the same examination. In contrast, PV values were about the same in both instances and were clearly within the pathologic range. For this reason, it is imperative that PV be calculated by means of PD and PL values obtained from the same freeze-frame image of a longitudinal section through the pyloric muscle. If only the largest PD measured on the contracted muscle and the largest PL determined in the relaxed state were used, PV would be overestimated.

In conclusion, we showed that our criterion of PV greater than or equal to 1.4 mL proved to help identify early HPS more accurately than any of the existing criteria, especially in young infants with a short history of vomiting and a small pyloric muscle mass. ■

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