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A Gastrointestinal PCR Panel Improves Clinical Management and Lowers Health Care Costs

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ABSTRACT Conventional methods for the identification of gastrointestinal pathogens are time-consuming and expensive and have limited sensitivity. The aim of this study was to determine the clinical impact of a comprehensive molecular test, the BioFire FilmArray gastrointestinal (GI) panel, which tests for many of the most common agents of infectious diarrhea in approximately 1 h. Patients with stool cultures submitted were tested on the GI panel ($n = 241$) and were compared with control patients ($n = 594$) from the year prior. The most common organisms detected by the GI panel were enteropathogenic *Escherichia coli* (EPEC, $n = 21$), norovirus ($n = 21$), rotavirus ($n = 15$), sapovirus ($n = 9$), and *Salmonella* ($n = 8$). Patients tested on the GI panel had an average of 0.58 other infectious stool tests compared with 3.02 in the control group ($P = 0.0001$). The numbers of days on antibiotic(s) per patient were 1.73 in the cases and 2.12 in the controls ($P = 0.06$). Patients with the GI panel had 0.18 abdomen and/or pelvic imaging studies per patient compared with 0.39 ($P = 0.0002$) in the controls. The average length of time from stool culture collection to discharge was 3.4 days in the GI panel group versus 3.9 days in the controls ($P = 0.04$). The overall health care cost could have decreased by $293.61 per patient tested. The GI panel improved patient care by rapidly identifying a broad range of pathogens which may not have otherwise been detected, reducing the need for other diagnostic tests, reducing unnecessary use of antibiotics, and leading to a reduction in hospital length of stay.

KEYWORDS PCR, clinical management, diarrhea, gastroenteritis, gastrointestinal infection, molecular panel, norovirus, salmonella, syndromic testing

Diarrheal diseases are a major cause of emergency department (ED) visits and hospitalization. The Centers for Disease Control and Prevention (CDC) reported that foodborne diseases account for approximately 76 million illnesses per year in the United States (1). Conventional methods for identification of a pathogen, for example, antigen tests, microscopic examinations, and culture, are time-consuming and expensive and have limited sensitivity. These limitations cause several downstream effects. Patients who may benefit from antibiotics may not receive them in a timely manner because an organism is not identified within a time frame that would be reasonable to initiate treatment. While awaiting results, patients with severe disease or complex clinical histories (i.e., numerous comorbidities) may be admitted to the hospital or undergo more invasive or expensive testing, such as colonoscopy or abdominal imaging studies. The CDC recommends that patients with suspected infectious diarrhea be

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put on contact precautions empirically (2); therefore, in the absence of laboratory results, patients may be isolated unnecessarily (3).

This study aimed to determine the clinical impact of a new comprehensive molecular panel, the FilmArray gastrointestinal panel (GI panel) (BioFire Diagnostics, Salt Lake City, UT). This PCR panel tests for many of the most common agents of infectious diarrhea, including bacteria, parasites, and viruses, in approximately 1 h. We hypothesized that patients with a sample tested on the GI panel would have a shorter length of hospital stay and decreased time on antibiotics, which are often not needed for many causes of gastroenteritis. Also, we sought to determine if the GI panel lessened the need for more invasive and expensive tests, and we used certain abdominal imaging studies as a marker of these. Many of the organisms on the GI panel are not routinely tested for, and this enabled us to determine the rate at which organisms were detected that would have otherwise not been found.

(Part of this research was presented in a poster at the American Academy of Clinical Chemistry Annual Meeting, San Diego, CA, July 2017.)

MATERIALS AND METHODS

Study population. This study took place at the University of Florida (UF) Health Shands Hospital, a 972-bed, tertiary care, academic medical center in Gainesville, Florida. The microbiology laboratory identified ED or admitted patients ($n = 241$) with stool samples submitted with an order for stool culture from 6 June 2016 to 5 June 2017. The sample that was submitted for stool culture was additionally tested on the GI panel. Physicians were not informed that the GI panel would be performed when they ordered a stool culture. Prior to implementation, there was no formal communication to providers that the evaluation was beginning; there was essentially no education regarding the new assay. Historical controls ($n = 594$) were those patients with stool cultures from 1 June 2015 to 31 December 2015. The following data were collected from the patients' medical records: age, gender, date of admission, date of discharge, disposition from the ED (admitted versus discharged), date/time of stool sample collection, and date/time of GI panel result in the GI panel patients or stool culture result in historical control patients. Patients with a length of stay greater than 14 days were excluded from our study. Additional stool tests, antibiotic days, and imaging studies were identified if they were performed within the patient's hospital stay after the stool collection. Additional stool tests included *Clostridium difficile* PCR in GI panel patients and *C. difficile* PCR, ova and parasite examination, *Giardia*/*Cryptosporidium* antigen enzyme immunoassay (EIA), *Microsporidia* stain, modified acid fast stain, rotavirus antigen EIA, Shiga-like toxin EIA, *Yersinia* stool culture, and *Vibrio* stool culture in the historical control patients. "Antibiotic days" comprised the number of days in which at least one dose of any of the following medications was given: erythromycin, azithromycin, ciprofloxacin, levofloxacin, trimethoprim-sulfamethoxazole, metronidazole, vancomycin, nitazoxanide, and ceftriaxone. Imaging studies included computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and X-ray, of the abdomen and/or pelvis. The pediatric study population included patients ≤18 years of age at the time of admission to the hospital. Length of stay (LOS) analyses excluded patients who were discharged directly from the ED or who died during admission. For patients included in LOS analyses, the LOS did include time spent in the ED.

Standard methods. All conventional tests that were ordered on the stool specimen were performed (unless excluded due to sample requirements), and results were released throughout the study period, regardless of initiation of the GI panel. Stool cultures were performed by inoculating blood, MacConkey agar, Hektoen enteric agar, campylobacter (CAMPY) agar, and Gram-negative broth. Non-lactose-fermenting organisms on MacConkey agar were further worked up with Gram staining, biochemical testing, spot tests, Vitek II (bioMérieux, Marcy l'Etoile, France) identification cards, and/or matrix-associated laser desorption–ionization time of flight mass spectrometry (MALDI-TOF MS) performed on the Vitek MS (bioMérieux, Marcy l'Etoile, France). *Vibrio* and *Yersinia* cultures were ordered and performed separately using specialized media. Ova and parasite examination included gross examination, concentrated wet preparation, and trichrome staining. Other assays included the Cepheid Xpert *C. difficile* assay (Cepheid, Sunnyvale, CA), the ImmunoCardStat! rotavirus assay (Meridian Biosciences, Cincinnati, OH), the ImmunoCardStat! enterohemorrhagic *Escherichia coli* (EHEC) assay (Meridian Biosciences, Cincinnati, OH) for Shiga toxins 1 and 2, *Giardia*/*Cryptosporidium* Quik Chek (Alere, Inc., Waltham, MA), and IBD EZ VUE (TechLab, Blacksburg, VA) for fecal lactoferrin. Of note, norovirus PCR must be ordered via a miscellaneous test order; this test is mailed to our reference laboratory.

FilmArray GI panel. The GI panel tests for *Campylobacter* (*C. jejuni*, *C. coli*, and *C. upsaliensis*), *Clostridium difficile* (toxin A/B), *Plesiomonas shigelloides*, *Salmonella*, *Yersinia enterocolitica*, *Vibrio* (*V. parahaemolyticus*, *V. vulnificus*, and *V. cholerae*), *Vibrio cholerae*, enteroaggregative *Escherichia coli* (EAEC), enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC) lt/st, Shiga-like toxin-producing *E. coli* Stx1/Stx2, *E. coli* O157, *Shigella*/enteroinvasive *E. coli* (EIEC), *Cryptosporidium*, *Cyclospora cayetanensis*, *Entamoeba histolytica*, *Giardia lamblia*, adenovirus F40/41, astrovirus, norovirus genogroup I/II, rotavirus A, and sapovirus (I, II, IV, and V). The assay was performed according to the manufacturer's instructions on a FilmArray 2.0 system. Hands-on time is less than 3 min, and run time is approximately 1 h. Tests were performed in real time or near real time on stool samples submitted from the ED or hospital ward with an order for a stool culture Monday through Friday, 7 a.m. to 3 p.m., and results were released into the

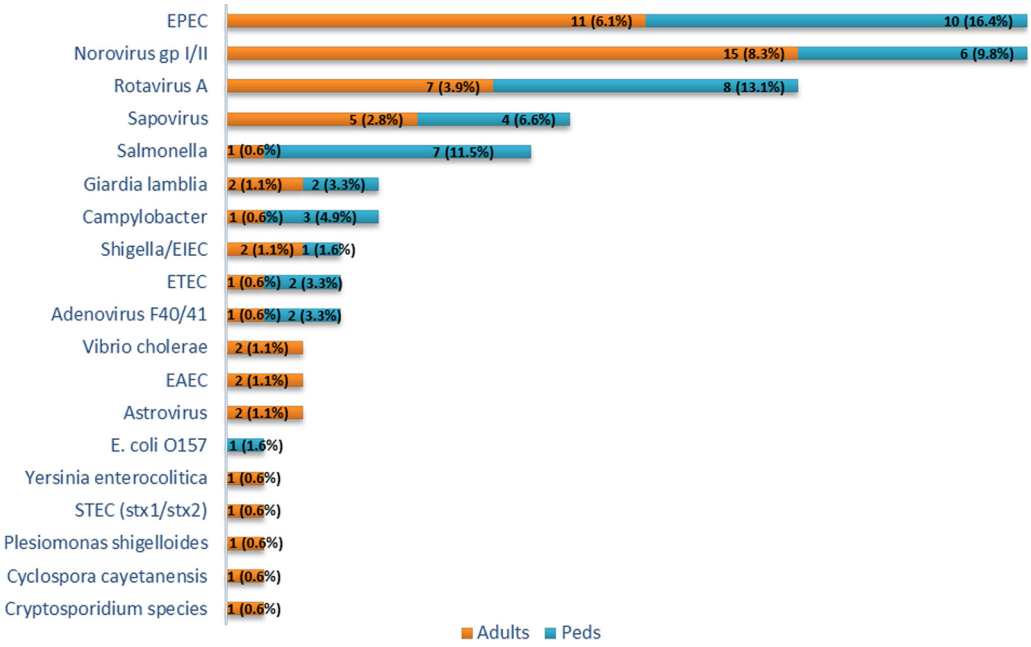

FIG 1 Distribution of organisms identified on the GI panel for adult and pediatric patients. A total of 241 samples were tested, and 79 (32.8%) were positive for a total of 103 organisms. Absolute numbers and percentages of positive tests within each age group are shown.

electronic health record (EHR). Results were accompanied by a statement regarding the product evaluation and, depending on the organism, a comment about the significance of the organism (see Table S1 in the supplemental material). The Department of Infection Prevention and Control also reviewed the results in real time during business hours via Theradoc (Premier, Inc., Charlotte, NC) to determine the appropriate level of isolation precautions. Results from the GI panel for *C. difficile* were not included in the EHR results.

Historical control population. Patients with stool cultures submitted in the year prior to implementation of the GI panel served as a historical control group. These patients were limited by stool culture collection Monday through Friday, irrespective of time (i.e., not limited to 7 a.m. to 3 p.m. like the intervention group). Additionally, patients with a length of stay of >14 days were excluded from the study.

Cost analysis. The cost per test for conventional tests is shown below (see Table 4). These costs are direct laboratory costs and do not include personnel time. The list price of the FilmArray GI panel is $155 per test. Hospital stay costs were approximated to be $800 per day, and radiology costs were as follows: X-ray, $55; ultrasound, $55; CT scan, $51; and MRI, $165 (as published by Sistrom and McKay [4]). All costs listed were irrespective of patient charges or reimbursement.

Data and statistics. Clinical data for endpoint variables were obtained from electronic medical records through the use of report writing software (SAP Business Objects).

Statistical analyses were conducted using SAS 9.3. Descriptive statistics and frequency tables were used to summarize our data, and unpaired *t* tests (Student's *t* test) were used to determine if there was a statistically significant difference in endpoint variables between our case and control populations. In SAS, we used "proc ttest" and obtained our *P* values via the "pooled" method. We used "proc univariate" to obtain descriptive statistics for our continuous dependent variables.

This project was registered in the University of Florida's Quality Improvement Project Registry (project ID 236).

RESULTS

A total of 241 patients (180 adults and 61 children) were tested on the GI panel. Figure 1 shows the distribution of all organisms identified. The most common organisms identified were EPEC ($n = 21$), norovirus ($n = 21$), rotavirus ($n = 15$), sapovirus ($n = 9$), and *Salmonella* ($n = 8$). All organisms on the GI panel, except *Entamoeba histolytica*, were identified at least once. The overall positivity rate was 32.8% (55.8% in pediatric patients versus 15.6% in adults).

There were 19 (7.9% of total and 24% of positive specimen) samples with more than one organism identified by the GI panel. Five of these had three organisms identified. There were numerous combinations of organisms, as shown in Table 1. EPEC was involved in 12 of these mixed infections.

TABLE 1 Mixed infections by age group[a]

Organisms[b]	No. of patients with infection	
	Adult	Pediatric
Campylobacter, EPEC		2
Rotavirus A, EPEC		2
EPEC, *Salmonella*, sapovirus		1
Giardia lamblia, EPEC, ETEC		1
Rotavirus A, *Salmonella*		1
Rotavirus A, sapovirus		1
Salmonella, adenovirus F40/41		1
Salmonella, EPEC, ETEC		1
Norovirus genotype I/II, *Giardia lamblia*	1	1
Norovirus genotype I/II, EPEC	2	
Norovirus genotype I/II, EPEC, *Salmonella*	1	
Shigella/EIEC, EPEC	1	
STEC, rotavirus A	1	
Vibrio cholerae, *Plesiomonas shigelloides*, EPEC	1	
Yersinia enterocolitica, sapovirus	1	
Total no. of patients with mixed infections/total in the age group (%)	8/180 (4.4)	11/61 (18)
Total no. of patients with mixed infections/no. of positive patients in the age group (%)	8/45 (17.8)	11/34 (32.4)

[a]A total of 19 (24% of positives) samples had two or more organisms.
[b]EPEC, enteropathogenic *E. coli*; EIEC, enteroinvasive *E. coli*; ETEC, enterotoxigenic *E. coli*; STEC, Shiga toxin-producing *E. coli*.

Table 2 shows the order frequency and percent positivity of conventional methods performed on patients tested by the GI panel. Of 4 patients who were positive for *Campylobacter* on the GI panel, 2 (50%) were positive by culture. The patient with *Cyclospora* found on the GI panel did not have a modified acid-fast stool smear ordered. Of the five patients with *Cryptosporidium* and *Giardia* identified by the GI panel, only 2 had an ova and parasite examination ordered, and samples from both patients were improperly collected and could not be tested. None of these patients had a *Cryptosporidium*/*Giardia* antigen EIA ordered. Of two patients found with *Vibrio cholerae*, one had a *Vibrio* stool culture ordered. The patient with Shiga-like toxin had an EIA ordered, which was negative. Of 15 patients with rotavirus, 2 had a rotavirus EIA ordered, both of which were positive. None of the 21 patients with norovirus had a norovirus PCR ordered.

TABLE 2 Frequency of order and percent positivity of conventional methods performed on patients tested by the GI panel[a]

Organism[b]	No. (%) of patients		
	Positive by the GI panel	With conventional testing method ordered	Positive by the conventional method
Salmonella spp.	8	8	7 (87.5)
Shigella spp.	3	3	2 (66.7)
Campylobacter spp.	4	4	2 (50)
Plesiomonas shigelloides	1	1	1 (100)
Vibrio cholerae	2	1	1 (50)
STEC (Stx1/Stx2)	1	1	0
Cyclospora cayetanensis	1	0	0
Cryptosporidium spp.	1	0	0
Giardia lamblia	4	2 by O&P	0
		1 by EIA	0
Rotavirus	15	2	2 (13.3)
Norovirus	21	0	0

[a]Both samples sent with an order for examination of ova and parasites (O&P) were improperly collected, and the test could not be performed.
[b]STEC, Shiga toxin-producing *E. coli*.

TABLE 3 Organisms identified by conventional methods in the historical control population[a]

Organism[b]	No. of historical controls positive/no. tested (n = 594)
EPEC	NT
Norovirus genotype I/II	NT
Rotavirus A	0/27
Sapovirus	NT
Salmonella spp.	20/594
Giardia lamblia	1/146
Campylobacter spp.	7/594
Shigella/EIEC	3/594
ETEC	NT
Adenovirus F40/41	NT
Vibrio spp.	1/27
EAEC	NT
Astrovirus	NT
Escherichia coli O157	0/41
Yersinia enterocolitica	0/46
STEC (Stx1/Stx2)	1/41
Plesiomonas shigelloides	0/594
Cyclospora cayetanensis	0/28
Cryptosporidium species	3/146
Entamoeba histolytica	0/274
Aeromonas hydrophila	2/594
Overall positivity rate (%)	6.7

[a]A total of 594 samples were tested, and 40 (6.7%) were positive for a total of 41 organisms. NT, not tested.
[b]EPEC, enteropathogenic *E. coli*; EIEC, enteroinvasive *E. coli*; ETEC, enterotoxigenic *E. coli*; EAEC, enteroaggregative *E. coli*; STEC, Shiga toxin-producing *E. coli*.

In the historical control cohort (n = 594), the positivity rate for conventional methods was 6.7% (3.4% in adults and 15.6% in pediatric patients). The most common organisms identified were *Salmonella* (n = 20) and *Campylobacter* (n = 7). The full distribution of organisms identified by various conventional methods is shown in Table 3. There was a single mixed infection (one sample with both *Giardia* and *Cryptosporidium* identified by EIA). The conventional tests that were performed and the cost per test are shown in Table 4. The average cost of testing per patient in the historical cohort was $61.18.

Table 5 shows demographics and clinical outcomes. The GI panel result was available in the EHR after an average of 8.94 h versus 54.75 h for stool culture results. Stool cultures which were positive for a pathogen often had a preliminary result available in the EHR in a shorter period of time, but these data were not captured. Patients with the GI panel had an average of 0.58 additional stool tests (*C. difficile* PCR) versus an average of 3.02 additional stool tests per patient (P = 0.0001) in the historical

TABLE 4 Conventional lab tests ordered for historical control population and average cost per patient[a]

Test	No. of orders	Cost per test ($)	Total cost in cohort ($)
Stool culture	594	6.69	3,973.86
Ova and parasite examination	274	18.98	5,200.52
Cryptosporidium/*Giardia* antigen test	146	40.36	5,892.56
Yersinia stool culture	46	4.97	228.62
Shiga-like toxin EIA	41	19.43	796.63
Cyclospora/*Isospora* stain	28	20	560
Vibrio stool culture	27	5.2	140.4
Rotavirus antigen test	27	8.36	225.72
C. difficile PCR	483	40	19,320
Total			36,338.31

[a]Total number of historical control patients, 594; average cost per patient, $61.18.

TABLE 5 Demographics, antibiotic days, stool tests, and imaging studies in GI panel patients versus historical controls

Variable[a]	Value for patient group		*P* value
	GI panel (*n* = 241)	Historical controls (*n* = 594)	
No. (%) of males	122 (50.6)	286 (48.2)	
Age (yr), mean (range)	41.37 (0–93)	41.66 (0–102)	
No. (%) of patients of pediatric age	61 (24.3)	147 (24.7)	
No. of additional stool tests (95% CL)	0.58	3.02 (2.89–3.14)	0.0001
No. of antibiotic days (95% CL)	1.73 (1.41–2.04)	2.12 (1.89–2.35)	0.06
No. of imaging studies (95% CL)	0.18 (0.10–0.26)	0.39 (0.31–0.48)	0.0002
Order to result time (h) (range)	8.94 (1.44–82.8)	54.75 (30.48–209.52)	<0.0001

[a]CL, confidence limit.

control group. Antibiotic days were 1.73 (95% confidence limit, 1.41 to 2.04) and 2.12 (95% confidence limit, 1.89 to 2.35) days per patient ($P = 0.06$) in the GI panel and historical control groups, respectively. Patients with the GI panel had 0.18 imaging studies per patient compared with 0.39 ($P = 0.0002$) studies per patient in the historical control group (Table 6).

A total of 222 patients with the GI panel and 505 historical control patients were included in the length-of-stay analysis (18 GI panel and 77 historical control patients were discharged from the ED; 1 GI panel patient and 12 historical control patients died during their admission). The average length of stay was 5.2 ± 3.2 days in the GI panel group versus 5.6 ± 3.4 days in the control group ($P = 0.14$). The time from stool collection to discharge was 3.4 ± 2.9 days in the GI panel group and 3.9 ± 3.1 days in the control group ($P = 0.04$). The LOS index (observed divided by Vizient expected) was 1.1 in the GI panel group versus 1.2 in the historical control group ($P = 0.11$). Twelve patients (5.4%) in the GI panel group were discharged before a result was available compared with 172 (34.1%) patients in the historical control group. Of these patients, 5 (2.3%) in the GI panel group and 18 (3.6%) in the historical group had a positive result unknown at the time of discharge. Details are shown in Table 7. Considering all the above factors, the total health care costs were estimated to be $293.61 per patient lower in GI panel patients than in historical controls (Table 8).

TABLE 6 Comparison of numbers of imaging procedures and costs in patients with the GI panel versus the historical control group

Test and patient group[a]	No. of patients	Cost ($)	Total cost ($)
Abdominal and/or pelvic X-ray			
GI panel patients	19	55	1,045
Controls	123	55	6,765
Abdominal and/or pelvic computed tomography			
GI panel patients	16	51	816
Controls	69	51	3,519
Abdominal and/or pelvic ultrasound			
GI panel patients	2	55	110
Controls	31	55	1,705
Abdominal and/or pelvic magnetic resonance imaging			
GI panel patients	6	165	990
Controls	10	165	1,650
Totals			
GI panel patients	241	12.29[b]	2,961[c]
Controls	594	22.96[b]	13,639[c]

[a]Abdominal and/or pelvic radiology studies were performed within the patient's hospital stay after the stool collection. Costs were published by Sistrom and McKay (4).
[b]Mean cost per patient.
[c]Total cost for patient group.

TABLE 7 Hospital LOS for GI panel patients versus historical controls

Variable	Value for[a]: GI panel patients	Historical controls	*P* value
Total no. of patients	241	594	
No. (%) of patients discharged from the ED	18 (7.5)	77 (12.9)	0.02
No. (%) of patients admitted	223 (92.5)	517 (87.0)	
No. (%) of patients that died during admission	1 (0.4)	12 (2.3)	0.12
Average LOS of inpatients, days (SD)	5.2 (3.2) (n = 222)	5.6 (3.4) (n = 505)	0.14
Pediatric patients	3.9 (2.7) (n = 55)	4.0 (3.1) (n = 110)	0.84
Adult patients	5.6 (3.2) (n = 167)	6.1 (3.4) (n = 395)	0.11
LOS after collection, days (SD)	3.4 (2.9) (n = 222)	3.9 (3.1) (n = 505)	0.04
Pediatric patients	2.6 (2.2) (n = 55)	2.7 (2.6) (n = 110)	0.81
Adult patients	3.6 (3.1) (n = 167)	4.3 (3.1) (n = 395)	0.01
LOS index (SD)	1.1 (0.61) (n = 176)	1.2 (0.73) (n = 479)	0.11
No. (%) of inpatients discharged before result	12 (5.4)	172 (34.1)	<0.0001
No. of patients with positive results unknown at time of discharge	5	18	
LOS (days) (SD) in patients with a result at time of discharge	5.2 (3.2) (n = 210)	7.0 (3.2) (n = 333)	<0.0001
LOS (days) (SD) after stool collection in patients with a result at time of discharge	3.5 (2.9) (n = 210)	5.3 (2.9) (n = 333)	<0.0001

[a]*n*, number of patients.

DISCUSSION

Our study evaluated 241 stool culture samples on the FilmArray GI panel. Results were released into the EHR. We then retrospectively analyzed downstream clinical management in these patients in comparison with a historical control population. We found that the GI panel had a high (32.8%) positivity rate which was similar to that of other published studies (5–8). Piralla et al. (9) tested 168 adult and pediatric patients with diarrhea and found an overall 54.8% positivity rate, with 28.3% having more than one organism. We found that 24% of positive samples had more than one organism. The slightly lower numbers seen in our study may be accounted for by *C. difficile*, which was reported in the study of Piralla et al. but not ours. They also only tested unformed stool samples, but we did not have this requirement.

Syndromic testing has been the standard of care for respiratory diseases for many years. In a point-counterpoint (10) discussion regarding respiratory panels, the counterpoint author stated that testing should be guided by clinical history and symptoms. This is certainly how physicians were previously taught to select from the myriad of tests available for gastroenteritis. Our study design allowed us to analyze the provider's orders with the GI panel result since they could not order the GI panel and did not know that they were going to obtain the GI panel result. Organisms that may have been missed included significant pathogens, such as *Campylobacter* in two patients, *Vibrio cholerae* in one patient, *Cyclospora* in one patient, Shiga-like toxin in one patient,

TABLE 8 Cost analysis[a]

Cost	Value for: GI panel patients	Historical controls	Cost difference per patient[b]
Mean hospital stay cost ($)	4,160	4,560	−400
Mean radiology costs ($)	12.29	22.96	−10.67
Mean laboratory testing costs ($)[c]	178.24	61.17	+117.06
Net difference per patient ($)			−293.61

[a]Even though in-lab expenses were higher in the GI panel group, these patients had a lower overall health care cost by $293.61 per patient.
[b]Cost for GI panel patient minus cost for historical control.
[c]Mean laboratory testing costs include the GI panel ($155) and *C. difficile* PCR ($40) at the rate of 0.58 tests per patient.

Giardia in four patients, both *Cryptosporidium* and *Giardia* in one patient, and norovirus in 21 patients. It is possible that the physicians had become used to seeing the results of the GI panel and assumed that they did not need to order the conventional tests; alternatively, they could have been using a stepwise approach to ordering, starting with a stool culture, and would have then progressed to additional tests if needed but did not need to do so because the result of the GI panel was released. One final possibility is that the *Campylobacter*, Shiga toxin, *Cryptosporidium*, and *Giardia* results identified by the GI panel were false positives, as they were not confirmed by conventional methods; however, this is unlikely, as these organisms fit well with the patients' clinical scenarios and the sensitivity of PCR is higher than that of culture, microscopy, or EIA (9). Stockmann et al. (7) retrospectively performed the FilmArray GI panel on 378 diarrhea samples which had been collected for *C. difficile* and/or other stool pathogen testing. In 91 patients who had a sample submitted only for *C. difficile* testing, the GI panel identified *Salmonella*, *Campylobacter*, norovirus, astrovirus, sapovirus, and *Giardia* alone or in combination with *C. difficile*. Similar to what was seen in our study, tests for these additional organisms were not otherwise done.

Our study analyzed clinical data with the goal of assessing the downstream impact of the test. Patients who had samples tested by the GI panel had fewer additional stool tests, fewer imaging studies, and fewer days on antibiotics. Since a large portion of the results did not require antimicrobial treatment, numerous patients were able to avoid additional days of antibiotic exposure and the associated adverse effects. Additionally, perhaps the GI panel result enabled the clinical team to choose not to pursue imaging studies in search of a reason for the patient's symptoms. One patient had previously been worked up extensively over a 6-month period for right upper quadrant pain with several colonoscopies, endoscopic retrograde cholangiopancreatographies (ERCP), upper endoscopies, and several other procedures and tests before coming to our hospital for evaluation. Her stool sample was submitted for stool culture and the GI panel identified *Cyclospora*. No further testing was performed, and she was discharged with appropriate treatment.

The overall length of stay decreased by 0.5 days in the GI panel group, as did the length of time from stool collection to discharge. It is likely that knowledge of the etiology of the patient's signs and symptoms allowed for prompt clinical management. As a large proportion of patients were negative for pathogens, this information may have allowed clinicians to pursue and treat other potential causes of gastrointestinal disease.

There are limited publications regarding cost savings with the use of any gastrointestinal pathogen panel. In our study, overall health care costs were $293.61 lower in the GI panel group. This is mostly attributable to a decreased length of stay. One study (11) performed in the United Kingdom used a parallel diagnostic model on 800 patients. They estimated that lab costs would have been an additional ~$34,800 if a multiplex PCR panel had been used instead of conventional testing but that there would have been a savings in isolation costs of ~$69,500. We were unable to collect isolation data due to the complexity of the isolation process and because of the numerous reasons for isolation. There were patients in our study who were found to have norovirus, rotavirus, and sapovirus who were not in isolation. Of note, we did not report *C. difficile* and therefore performed an additional test when ordered. Cost savings might be more substantial if *C. difficile* had been reported from the GI panel. Of note, personnel time was not calculated in the cost analysis. If the GI panel had been used instead of conventional methods, medical technologist time may likely have been saved or (more likely) utilized for other laboratory tests.

Our study has several limitations. We did not inform clinicians that we were performing the GI panel at the time of stool culture order entry, and the GI panel results were not actively communicated to the provider, so the clinicians may not have thought to follow up on the stool culture result within hours of submitting the sample. We did not confirm results in which the GI panel and the conventional testing did not

agree. Finally, we used a historical cohort of patients to serve as a control group; a randomized controlled trial would have been superior.

Subjective feedback from the hospital medical staff and the medical technologists was overwhelmingly positive. After the study concluded and the lab no longer performed the GI panel, the lab received several calls requesting it. Numerous patients with acute gastroenteritis do not ever have an infectious disease workup ordered because of the low sensitivity and long turnaround time of conventional diagnostic methods (12), but we speculate that these newer, more rapid, and comprehensive methods may lead to increased stool testing and pathogen identification.

Conclusions. Multiplex gastrointestinal panels have the potential to increase the detection of important pathogens. This coupled with a rapid turnaround time has several downstream effects, such as more appropriate use of antibiotics and isolation. Knowledge of the etiology of the patient's symptoms was associated with shorter length of stay and fewer imaging studies. Although in-lab costs increased with the use of the GI panel, our study observed a decrease in overall health care costs.

SUPPLEMENTAL MATERIAL

Supplemental material for this article may be found at https://doi.org/10.1128/JCM.01457-17.

SUPPLEMENTAL FILE 1, PDF file, 0.3 MB.

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