Evaluation of Protocol Using Gene Capture and PCR for Detection of *Helicobacter pylori* DNA in Feces

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*Helicobacter pylori* is one of the most common bacterial pathogens of humans (8). Primarily acquired in early life, it can be associated with both malnutrition (17) and growth retardation in children (14). Colonization is usually lifelong and may lead to chronic gastritis, duodenal ulceration (12), and gastric cancer in later life (4).

Despite many years of research into *H. pylori*, its mode(s) of transmission is not fully understood. Epidemiological studies have demonstrated the importance of close person-to-person contact and intrafamilial spread (3), but it remains uncertain whether transmission occurs primarily through the fecal-oral or gastric-oral route (13).

Publication of the complete genome sequence of *H. pylori* (21) and advances in molecular genotyping methods make possible the genotypic analysis of *H. pylori* DNA isolates within individuals, families, and communities (2). Studies suggest that transmission within families occurs most readily between siblings of similar ages (6) and is uncommon between couples (18). However, many questions remain unanswered, such as the relative importance of vertical or horizontal transmission and the risk of transmission from outside the family group. Large-scale genotyping studies could answer some of the epidemiological questions, but these are difficult to perform, mainly due to a lack of easily accessible *H. pylori* DNA.

*H. pylori* DNA is currently obtained during endoscopy (or a string test) from the stomach either directly or following bacterial culturing. These methods are invasive and inappropriate for studies involving children, which would be of particular epidemiological interest.

Fecal material could provide an easily accessible source of *H. pylori* DNA. *H. pylori* has been cultured from the feces of experimentally colonized individuals (13) and from children in The Gambia (20), but such culturing does not appear to be easy for the majority of patients. Several studies have detected *H. pylori* antigens in fecal material (15, 22, 23), but this technique cannot provide information beyond the presence or absence of antigens.

Although *H. pylori* colonizes only the stomach, it must pass through the intestine in a viable form, as it has been reported to colonize Meckel’s diverticulum and other sites of acid-secreting epithelium (5). Its fate during further passage in the gastrointestinal tract remains unclear (25). Reported success rates for the detection of *H. pylori* DNA in feces vary from 25 to 100% (9, 16, 24). This variability is probably due to *H. pylori* degradation in the gastrointestinal tract and/or the presence of inhibitors.

Human feces contain inhibitory compounds of bacterial and/or plant origin, such as complex polysaccharides, that readily inhibit the further processing of purified DNA (10). Diets free of fruit and vegetables can reverse fecal inhibition (11), but such regimens are inappropriate for large-scale genotyping studies. A number of DNA purification methods have been developed to remove inhibitors; these involve organic extraction and ethanol precipitation (7), the use of macro-porous polypropylene filters (1), and modified commercial kits. All of them have met with varying success, and a standardized method for the optimal recovery of *H. pylori* DNA isolates from feces has yet to be developed.

Recently, Shuber et al. (16) published a protocol that specifically enriches *H. pylori* DNA from complex fecal DNA mixtures. So far, this technique has demonstrated (for a small number of subjects) 100% sensitivity and specificity (16). Although this new technique showed promise, it included a proprietary initial purification step that may have hindered other groups from repeating the work. Here we describe the development of a nonproprietary, noninvasive *H. pylori* DNA puri-
fication protocol that is suited to studies involving children and that should open the way to the genotyping of *H. pylori* within families.

**MATERIALS AND METHODS**

**Subjects.** Based on the results of the 13C-urea breath test (UBT), 30 children (15 positive and 15 negative for *H. pylori*) were studied. They were selected from children attending the Royal Hospital for Sick Children (Glasgow, Scotland) for a UBT as part of an investigation of gastrointestinal problems.

**UBT.** Following an overnight fast, each subject ingested an oral dose of 100 mg of 13C-urea (99 atom% excess; CK Gas, Berks, United Kingdom), administered in 20 ml of 15% Polycose (Abbott Laboratories, Dublin, Ireland). Baseline breath samples were collected by asking the subject to blow into a straw into an Exetainer (Labco, High Wycombe, United Kingdom) before and at 30 and 45 min after ingestion of the labeled urea. The abundance of 13C in breath CO2 was measured by continuous-flow isotope ratio mass spectrometry (20/20; PDZ Europa, Crewe, United Kingdom) against a reference gas (3% CO2 in N2; Air Products Special Gases, Crewe, United Kingdom), which was calibrated against a secondary reference traceable to the international standard (Vienna Pee Dee Belemnite). The enrichment of the postdose sample was calculated by subtracting the abundance of the baseline sample from that of the postdose sample. An excess of 13C enrichment of more than 400 ppm (delta over baseline, 3.5% 13C) was regarded as indicative of *H. pylori* colonization (19).

**Fecal analysis.** Each child provided a fecal sample from home by using a collection device, which fitted over the toilet, to transfer the sample directly into a sterile plastic bag. Immediately after collection, fecal samples were stored at −80°C until analysis.

An initial analysis for the presence of *H. pylori* in feces was performed by using an enzyme immunoassay as directed by the manufacturer (Premier Platinum HpSA; Meridian Diagnostics Inc., Cincinnati, Ohio). Briefly, diluted fecal samples and a peroxidase-conjugated polyclonal antibody were added to microwells coated with anti-*H. pylori* antibodies and incubated for 1 h at 24°C. The wells were cleansed with wash buffer (supplied in the kit) to remove any unbound material, and a substrate solution was added before a further 10 min of incubation. The reaction was stopped by the addition of a stop solution (sulfuric acid), and the absorbance was measured spectrophotometrically at 450 nm (Multiskan Plus; Thermo Life Sciences, Basingstoke, United Kingdom) (15).

For DNA analysis, fecal samples were thawed and processed immediately by homogenization in sterile phosphate-buffered saline (0.01 M phosphate buffer, 0.005 M potassium chloride, 0.317 M sodium chloride, [pH 7.4]) in a homogenizer 400 (Seward Medical, London, United Kingdom) for 10 min at room temperature to produce 20% (wt/vol) fecal slurries.

Fecal slurries were centrifuged at 20,000 × g for 30 min (Heraeus Biofuge Stratos centrifuge; Kendro Laboratory Products, Sollentum, Germany), and the supernatant was removed carefully so that the pellet was left undisturbed. Previous studies had shown that *H. pylori* was concentrated in a cream-colored layer at the top of the pellet (12), which was removed by using a plastic Pasteur pipette. The suspension was transferred to a sterile 2-ml microcentrifuge tube (Hybaid, Middlesex, United Kingdom) and modified by the addition of an equal volume of PrepNet Ultra (Applied Biosystems, Cheshire, United Kingdom), which has been formulated for the removal of PCR-quality DNA from foodstuffs. Samples were boiled for 10 min, allowed to cool for 2 min, and then centrifuged at 20,000 × g for 10 min (Heraeus Biofuge Stratos) to pellet the particulates.

Total nucleic acid was separated from the protein by the phenol-chloroform-isoamyl alcohol (PCI) method with modifications as follows. Fecal concentrates were modified by the addition of an equal volume of PCI (25:24:1; Sigma-Aldrich, Dorset, United Kingdom) and mixed by inversion before centrifugation at 20,000 × g for 3 min (EBA 12 Centrifuge; Hettich Zentrifugen, Tuttingen, Germany). The upper (aqueous) phase was transferred to a fresh 2-ml microcentrifuge tube, and the process was repeated once more. Trace PCI was removed from the aqueous phase by treatment as described above but with the addition of chloroform instead of PCI. Total nucleic acid was harvested by precipitation with 0.1 volume of ice-cold 3 M sodium acetate and 2 volumes of ice-cold 100% ethanol (Sigma-Aldrich). Precipitation was performed on ice for 30 min and followed by centrifugation at 16,000 × g for 15 min (EBA 12 Centrifuge), air drying, and resuspension of samples in 266 μl of ultrapure water (Sigma-Aldrich). RNA was removed by the addition of 40 U of RNAse ONE (Promega, Southampton, United Kingdom) and incubation for 1 h at 37°C. The enzyme was removed by precipitation with sodium acetate and ethanol as described above.

Gene capture was performed by using an *H. pylori*-specific biotinylated capture probe (HpS1) [5-GGG GAC TGT CCG CAG ATT AAA ACTCAA CAA AGG ATAT 3′], which targeted the 16S rRNA gene of *H. pylori* (16) and which was supplied by Cruachem (Glasgow, United Kingdom). Total fecal DNA suspensions were mixed with 300 μl of 6 M guanidine thiocyanate (Sigma-Aldrich) and 20 mM of the capture probe and incubated overnight at 25°C. *H. pylori* DNA sequences were harvested by using 10 μl of paramagnetic polystyrene beads coated with Streptavidin (Dynabeads M-280—Streptavidin; Dynal ASA, Oslo, Norway) and washed three times in wash buffer (0.1 M Tris-HCl, 0.01 M EDTA, 1 M sodium chloride, 0.1% [vol/vol] Tween 20; Sigma-Aldrich). Final harvesting was performed at 85°C (for 6 min), and *H. pylori* DNA was transferred to a clean tube.

PCR reagents were supplied by AbGene (Surrey, United Kingdom). Each PCR consisted of reaction buffer, 1.5 mM MgCl2, 200 μM deoxynucleoside triphosphates, forward and reverse primers at 0.5 μM each, 1.25 U of Hotstart polymerase, and 10 μl of target DNA (final reaction volume, 50 μl). The following primers were synthesized by Cruachem: HpF (5-GGC TGC TGG AAC ATT A-3′) and HpR (5-GGT TAG CTC GAT TAC TGG AGA-3′) (7). All experiments included both a positive control (purified *H. pylori* DNA) and a negative control (the template DNA was substituted with sterile water).

Thermal cycling was performed with a PTC-200 Peltier thermal cycler (MJ Research, Waltham, Mass.). The thermal cycling parameters were as follows: an initial denaturation at 94°C for 15 min (prolonged heating at this temperature was required to activate the Hotstart DNA polymerase enzyme); 40 cycles of denaturation at 94°C for 1 min, annealing at 60°C for 1 min, and extension at 72°C for 1 min; and a final extension at 72°C for 5 min. All PCR products were analyzed by gel electrophoresis in a 3% (wt/vol) agarose gel (containing 0.6 μg of ethidium bromide ml−1) in 0.5× Tris-acetate—EDTA buffer. Electrophoresis was carried out for 1 h at 50 V (RunOne electrophoresis chamber; Electrobe, San Diego, Calif.), and DNA bands were examined under UV illumination.

One *H. pylori* strain, five nonpyloric Helicobacter strains, and one Campylobacter jejuni strain were cultivated on Columbia blood agar base (Oxoid, Hants, United Kingdom) supplemented with 7% defibrinated horse blood (TCS Biosciences, Buckingham, United Kingdom) for 7 days under microaerobic conditions (37°C) in gas jars (Becton Dickinson, Oxford, United Kingdom). The total biomass was harvested, resuspended in phosphate-buffered saline, and enumerated by microscopy (at a magnification of ×1,000 [phase contrast]) under oil immersion with an Axioscope microscope (Leica Microsystems, Milton Keynes, United Kingdom) and a cell counting chamber (Sigma-Aldrich) according to the manufacturer’s instructions.

The specificity of the PCR alone was determined with 1-μl volumes of cultivated bacterial cells. The specificity of the assay (DNA purification followed by PCR) was determined by seeding 20% fecal slurries made from samples from an *H. pylori*-negative control subject (as determined by the UBT and HpSA test) with bacterial cells. The resultant fecal slurries were purified, and the DNA was subjected to PCR.

The sensitivity of the assay was determined by seeding fecal slurries made from samples from an *H. pylori*-negative control subject (determined by the UBT and HpSA test) with serial dilutions of *H. pylori* cells. The resultant slurries were purified, and the DNA was assayed by PCR. The sensitivity was defined as the lowest concentration of *H. pylori* cells (per gram of feces) that resulted in PCR amplification.

**RESULTS**

Based on the results of the UBT, 30 children (15 positive and 15 negative for *H. pylori*) were selected for the study. They differed in no significant way in sex, age, or socioeconomic status. Fourteen children were positive and 14 were negative in both the UBT and the HpSA test. One child was UBT negative but HpSA test positive, and one child was UBT positive but HpSA test negative. There were no equivocal HpSA test results. The positive and negative predictive values were 93% (Fig. 1).

Twelve children were positive and 14 were negative in both the UBT and PCR. One child was UBT positive but HpSA test and PCR negative, and one child was UBT and PCR negative but HpSA test positive. Two children were positive in the UBT and HpSA test but negative in PCR. The positive predictive value was 80%, and the negative predictive value was 100% (Fig. 1).
The PCR assay amplified DNA directly from one (*H. paenetransis*) out of the five nonpyloric *Helicobacter* strains and one *C. jejuni* strain tested. Fecal slurries made from samples from an *H. pylori*-negative subject and seeded with these species did not yield positive PCR results following DNA purification. The limit of sensitivity of the assay was $10^5$ *H. pylori* cells/g of feces (Fig. 2).

**DISCUSSION**

The development of noninvasive tests for *H. pylori* has traditionally concentrated on diagnostic tests because of a reluctance to perform invasive procedures on young individuals unless absolutely necessary. Noninvasive tests report the presence or absence of *H. pylori* but provide no further information, such as which genotypes are present. The ability to genotype *H. pylori* from children without the need for invasive procedures would be a major advance and would make possible both the surveillance of *H. pylori* in families and the detection of antibiotic resistance in patients whose treatment has failed, without the need for a second endoscopy. There is also the possibility of screening for the presence of virulence genes in asymptomatic carriers so that the risk of later complications can be determined. For all of the above reasons, there is a need to develop noninvasive robust methods for harvesting *H. pylori* DNA from colonized subjects.

We utilized a PCR protocol developed by Gramley et al. (7) to determine the efficacy of a novel fecal DNA purification method that was reported by Shuber et al. (16) and that utilized several steps (including gene capture) to yield pure *H. pylori* DNA for PCR analysis. The original protocol developed by Shuber et al. (16) included an initial fecal cleanup step, which was the intellectual property of the Exact Science Corporation (Maynard, Mass.). We replaced this step with a novel system for initial fecal cleanup that involved concentrating bacteria from fecal slurries by centrifugation, a procedure which previous work had shown could be used to culture bacteria from feces (20).

The PCR used in this study (7) amplified DNA directly from one nonpyloric *Helicobacter* strain (Fig. 2). However, fecal slurries seeded with bacteria closely related to *H. pylori* and subjected to DNA purification did not yield any positive PCR results. The gene capture step used during DNA purification was selective for *H. pylori*. The assay developed during this study was also found to be a sensitive tool, with a limit of sensitivity of $10^5$ *H. pylori* cells/g of feces (Fig. 2).

Using feces from children with a known *H. pylori* status, we investigated the efficacy of this new protocol for the recovery of PCR-quality *H. pylori* DNA. The *H. pylori* status of the children was determined by using the UBT, which is the standard noninvasive diagnostic test (19). The presence or absence of *H. pylori* in feces was verified by using the HpSA fecal antigen test (15). A comparison of the three assays demonstrated a high degree of agreement. However, both the HpSA test and PCR failed to detect the presence of *H. pylori* in the feces of one and three UBT-positive children, respectively (Fig. 1). The lack of agreement between the HpSA test and PCR suggests that the problem was not the intermittent shedding of *H. pylori*. The finding of children who were UBT positive but PCR negative may indicate that in 20% of our cases, the purification protocol failed to provide DNA of adequate quality and/or quantity for analysis. In contrast, Shuber et al. (16) reported a positive predictive value of 100% for adult feces.

Children’s feces are more difficult to work with because of a greater variety in volume and consistency, and our failure to

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**FIG. 1.** Data set showing results for *H. pylori* PCR compared to the UBT and the HpSA test. The overall positive and negative predictive values for the HpSA and PCR compared to the UBT were 93 and 93%, respectively, and 80 and 100%, respectively.
obtain a positive predictive value of 100% may have been due to the quality of the fecal samples studied. Further work is under way with a larger number of children to investigate the effect of sample quality and to improve the positive predictive value of this novel extraction method.

For investigation of the feces of UBT-negative children, the PCR assay had a negative predictive value of 100%, while that for the HpSA test was 93%; these results suggest that the fecal PCR assay may be a more reliable tool than the HpSA test for verifying the successful eradication of *H. pylori* following antibiotic therapy (Fig. 1).

We conclude that fecal DNA purification involving gene capture coupled with PCR is an effective tool for obtaining *H. pylori* DNA from the feces of children.

This method has the potential to be a useful tool for investigating the genotypes of *H. pylori* harvested from feces. It should allow the study of genotypes of *H. pylori* in families to determine the route of transmission of this important human pathogen.

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**REFERENCES**


