

Novel 180- and 480-Base-Pair Insertions in African and African-American Strains of *Helicobacter pylori*

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Helicobacter pylori is a genetically diverse bacterial species that chronically infects human stomachs and sometimes causes severe gastroduodenal disease. Studies of polymorphic DNA sequences can suggest geographic origins of individual strains. Here, we describe a 180-bp insertion (ins180), which is just after the translation stop of a gene of unknown function, near the promoter of *jhp0152-jhp0151* two-component signal transduction genes in strain J99, and absent from this site in strain 26695. This ins180 insertion was found in 9 of 9 Gambian (West African), 9 of 20 (45%) South African, and 9 of 40 (23%) Spanish strains but in only 2 of 20 (10%) North American strains and none of 20 Lithuanian, 20 Indian, and 20 Japanese strains. Four South African isolates that lacked ins180 and that belonged to an unusual outlier group contained a 480-bp insertion at this site (ins480), whereas none of 181 other strains screened contained ins480. In further tests 56% (10 of 18) of strains from African Americans but only 17% (3 of 18) of strains from Caucasian Americans carried ins180 ($P < 0.05$). Thus, the *H. pylori* strains of modern African Americans seem to retain traces of African roots, despite the multiple generations since their ancestors were taken from West Africa. Fragmentary ins180-like sequences were found at numerous sites in *H. pylori* genomes, always between genes. Such sequences might affect regulation of transcription and could facilitate genome rearrangement by homologous recombination. Apparent differences between African-American and Caucasian-American *H. pylori* gene pools may bear on our understanding of *H. pylori* transmission and disease outcome.

Helicobacter pylori is a gram-negative microaerophilic bacterium that chronically infects the human gastric mucosa, typically for years or decades (8, 13, 19). It can cause a spectrum of gastroduodenal diseases including peptic ulcer and gastric cancer (8, 13) and has been designated a class I carcinogen by the World Health Organization (13). *H. pylori* acquisition occurs mostly in childhood (10, 36), often via maternal transmission (12, 24, 36).

Extensive geographic differences have been found in DNA sequences from *H. pylori* strains from different human populations (11, 14, 20, 24, 41). This led to a proposal that historical patterns of human migration and of racial admixture can be predicted from DNA sequences of *H. pylori* housekeeping

genes (14, 41). An ability to discern *H. pylori* lineages from distinct human populations should also have medical relevance, because disease outcomes associated with *H. pylori* infection vary geographically (22, 27, 28, 38, 39), and some of this might stem from genetic differences between *H. pylori* populations (25, 26, 37).

More than 80% of Africans are infected with *H. pylori*, but their gastric cancer rates are lower than might be predicted based on this high prevalence (6, 22, 25–28, 38, 39). Infection rates in North America and Europe are often less than half of those in Africa, but yet distal gastric carcinoma is more common in these regions (22, 38, 39), a discordance referred to as the “African Enigma” (22). Gastric cancer rates also vary by country in Asia (29). Those in Japan and Korea are remarkably high (male, 82.7/100,000, and female, 32.8/100,000), some 10- to 20-fold higher than in Thailand and 100-fold higher than in India (29), whereas *H. pylori* seroprevalences in these south Asian countries are higher than those of Japan and Korea. This discordance is referred to as the “Asian Enigma” (29). These discordances have been ascribed variously to societal, human, bacterial genetic, and environmental factors, including concurrent helminth infections (the frequency of which varies among societies) (18, 25, 26, 27).

Although overall rates of gastric adenocarcinoma have decreased in the United States over the last 60 years (2), those in African-American, Hispanic, and Native American popula-

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TABLE 1. Prevalence of ins180 and ins480 in the *jhp0153-jhp0152* intergenic region among a panel of *H. pylori* clinical isolates from geographically and ethnically diverse source patients

| Parameter | Lithuanian | Indian | Japanese | Gambian | South African | North American ^a | Spanish ^b | African American ^c | Caucasian American ^c |
|-----------------------|------------|--------|----------|---------------------------------|--------------------------------|-----------------------------|--------------------------------|--------------------------------|---------------------------------|
| No. of strains tested | 20 | 20 | 20 | 9 | 20 | 20 | 40 | 18 | 18 |
| No. ins180 positive | 0 | 0 | 0 | 9 (100%) (<i>P</i> < 0.001) | 9 (45%) (<i>P</i> < 0.001) | 2 (10%) | 9 (23%) (<i>P</i> < 0.001) | 10 (56%) (<i>P</i> < 0.05) | 3 (17%) |
| No. ins480 positive | 0 | 0 | 0 | 0 | 4 (20%) (<i>P</i> < 0.001) | 0 | 0 | 0 | 0 |

^a Patient cohort largely Caucasian from central Tennessee; however, patient data are incomplete.

^b Five ins180-positive strains possessed the *cag* PAI, and four did not.

^c Isolates from age- and gender-matched patients living in central Tennessee.

tions remain two to three times those in the Caucasian population (15). Again, much of this difference may stem from environmental, societal, or human genetic factors, but we infer that *H. pylori* genetic differences could also be important, i.e., disease outcomes might be affected by population differences in gene content or gene regulation in predominant *H. pylori* strains. Here we characterize 180-bp and 480-bp sequences (ins180 and ins480, respectively) found just downstream of a highly conserved but function-unknown gene and near a promoter of two-component signal transduction genes in a subset of *H. pylori* strains, positions that might allow it to affect expression of either the upstream or downstream genes. The 180-bp insert, in particular, was more common in strains from Africans and African Americans than in those from other human populations. ins480 was found only in an unusual outlier subset of South African strains.

MATERIALS AND METHODS

Bacterial strains and culture conditions. *H. pylori* strains were cultured on Trypticase soy agar II plates with 5% sheep blood (BBL) at 37°C in humidified ambient air containing 5% CO₂. All strains used here were from our lab collections (M.H.F., R.M.P., and D.E.B.), and most have been described previously (7, 23, 31–34).

Among Lithuanian isolates (*n* = 20), 18 contained the *cag* pathogenicity island (PAI) and two did not. Twelve of the Lithuanian source patients were diagnosed with gastritis, six were diagnosed with duodenal ulcer, and two were diagnosed with gastric ulcer. Isolates from India (*n* = 20) each contained the *cag* PAI and were each from patients diagnosed with duodenal ulcer. All Japanese isolates (*n* = 20) contained the *cag* PAI and included strains from patients with gastric carcinoma (*n* = 4) and gastritis only (*n* = 4). All 29 African strains (9 Gambian and 20 South African) were from black Africans with gastric complaints. Four of nine Gambian patients had duodenal ulcer, and 2 of 20 South African patients had gastric or prepyloric ulcers. In addition, seven of nine Gambian and 14 of 20 South African strains contained the *cag* PAI and the other two Gambian and six South African strains did not. North American *H. pylori* isolates used in this study included 30 that contained and 24 that lacked the *cag* PAI. Included were 18 strains from African Americans. Clinical diagnoses of source patients included gastritis, gastric ulcer, gastric erosions, duodenal ulcer, esophagitis, and Barrett's esophagus. Spanish isolates (*n* = 40) were from patients with gastric complaints, and 24 strains contained the *cag* PAI and 16 did not.

Molecular biology techniques. Genomic DNA was extracted using cetyltrimethylammonium bromide (CTAB), a cationic detergent, essentially as described previously (5). Briefly, 24- to 48-h *H. pylori* cultures were harvested from solid medium into 0.9% NaCl solution, and cell lysis was accomplished by addition of sodium dodecyl sulfate to a final volume of 0.5% and incubation at 37°C for 30 min. A 5 M concentration of NaCl was added to a final concentration of 725 mM, followed by 0.144 volume of 10% CTAB–0.7 M NaCl detergent. Bacterial lysates were phenol-chloroform and chloroform extracted, and genomic DNA was isopropanol precipitated using 0.86 volume of isopropanol, washed with 70% ethanol, and resuspended in 10 mM Tris, pH 8.5. PCR was performed using *Taq* DNA polymerase (Promega) and manufacturer-provided reaction buffer. Reaction mixtures consisted of 1× Mg²⁺-free polymerase reaction buffer, 2 mM

MgCl₂, 0.8 mM deoxynucleoside triphosphates (200 nM dATP, 200 nM dTTP, 200 nM dGTP, and 200 nM dCTP), 400 ng of each oligonucleotide, 200 ng of template DNA, and 1.25 U of *Taq* DNA polymerase in a final reaction volume of 50 μl. Amplification conditions consisted of a 5-min hot start and 25 to 30 cycles as follows: 94°C for 30 s, 56°C for 30 s, and 72°C for 1 min. The oligonucleotide primers used to amplify ins180-ins480 were insFwd, 5'-GTGGCGCGT TTCTTGCAATACC-3', and insRev, 5'-AACTCGCTCAAAAACCTGGC-3'. Cloning of PCR amplicons was accomplished using pGEM-T Easy and T4 DNA ligase (Promega). Plasmids were prepared using Qiagen spin columns, and restriction enzyme digestions were performed according to standard protocols (4). PCR analysis of the intergenic region of *jhp0153* to *jhp0152* was performed on 164 different *H. pylori* clinical isolates to determine the prevalence of the 180-bp and 480-bp insertions. One hundred forty-nine of these strains were from a global collection, and the others were from age- and gender-matched African-American (*n* = 18) and Caucasian (*n* = 18) patients in Tennessee (Table 1). Before running these tests, the researcher carrying them out was unaware of the origin of each of these 36 isolates.

DNA sequencing. PCR products destined for sequencing were purified using a Qiagen PCR purification kit. DNA sequencing reactions performed on the purified amplicons were accomplished using Big Dye Terminator version 3.1 (Applied Biosystems, Inc.) and the sequencing reaction mixture described by the manufacturer. The cycling conditions were 94°C for 5 min, followed by 26 cycles of 94°C for 45 s, 50°C for 30 s, and 60°C for 4 min. Excess dye terminators were removed with DTF gel filtration cartridges (Edge Biosystems) according to the manufacturer's protocol. Sequencing was performed at the College of William and Mary on an ABI Prism 3100 genetic analyzer.

Nucleotide sequence accession number. The sequences of ins180 and ins480 elements, determined here, have been deposited in GenBank (accession numbers AY731183, AY731182, and AY669071).

RESULTS

ins180 and ins480 in the *jhp0153-jhp0152* intergenic region: inserted DNAs that are most common in African *H. pylori* strains. Comparison of the large intergenic region between two-component signal transduction genes *jhp0152-jhp0151* and the conserved function-unknown gene *jhp0153* of *H. pylori* strain J99 with the corresponding region of strain 26695 (between genes *hp0166-hp0165* and *hp0167*) revealed a 180-bp segment (ins180) in J99 that was absent from the corresponding site in 26695. A BLAST search of this ins180 sequence against the complete *H. pylori* genome sequences revealed several smaller sequences of about 32 to 75 bp that were well matched to ins180 (>78% match; E value, ≤1 × 10⁻⁴) at 13 sites in the J99 genome (Fig. 1) and five sites in the 26695 genome (two of them at sites also identified in J99, downstream of *jhp0643* and *jhp1211* in Fig. 1). Every one of the 16 sequences so identified was between genes, not within them. Seven of the 13 in strain J99 were between 3' ends of convergently transcribed genes, five were between the 3' and 5' ends of neighboring genes transcribed in the same direction (as with

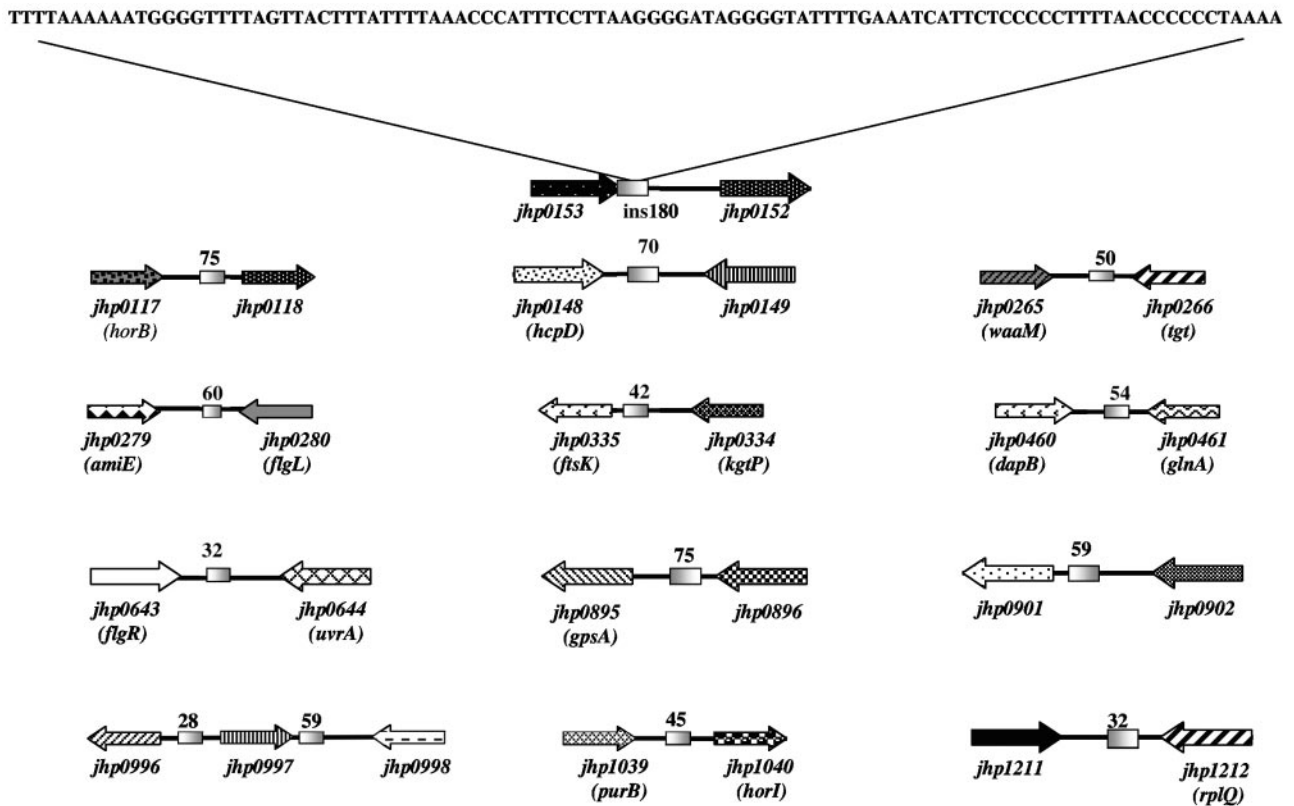


FIG. 1. ins180 contains a highly repetitive element. A 99-bp subsequence of ins180 is shown. This sequence, internal to ins180, contains all subsequences found in 13 other intergenic regions of *H. pylori* J99 and which along with ins180 are represented as shaded boxes between adjacent open reading frames. The numbers above each box represent the length (in base pairs) of ins180 subsequence found at each location. Each ins180 subsequence region was identified by BLAST search, and each had an E value of $\leq 1 \times 10^{-4}$. Typical percent homologies between these subsequences and ins180 were from 78 to 100. All genes with predicted functions are designated with three-letter gene designations within parentheses. Those genes without such designations were predicted to encode hypothetical proteins (1).

canonical ins180 in the *jhp0153-jhp0152* site), and one was between the 5' ends of divergently transcribed genes.

To better assess if canonical ins180 is unique to strain J99 or widespread in *H. pylori* populations (or if the corresponding deletion is unique to strain 26695 or common), we surveyed the *jhp0152-jhp0153* (*hp0166-hp0167*) intergenic regions of 149 strains from several geographic regions, using primers for sites flanking the ins180 insertion site (Fig. 2) and scoring either the presence or absence of ins180 based on formation of 530-bp or 350-bp amplicons, respectively (Fig. 3A, lanes 2 and 3). Of the *H. pylori* strains tested, all those from Lithuania ($n = 20$), India ($n = 20$), and Japan ($n = 20$) lacked ins180, whereas all nine Gambian strains and 45% (9 of 20) of South African strains carried ins180 at this locus ($P < 0.001$), as did 23% of Spanish *H. pylori* strains (9 of 40). Among Spanish strains, 5 of 24 that carried the virulence-associated *cag* PAI and 4 of 16 that lacked the *cag* PAI carried ins180. Two of 20 U.S. strains also carried this element (Table 1).

Four of the South African strains that lacked ins180 contained an even larger (480-bp) segment in this region (Fig. 3A, lane 1). Separate multilocus sequence typing (G. Dailide and D. E. Berg, unpublished data) has shown that these four strains belong to an outlier *H. pylori* type, which has been postulated variously to have evolved in an animal host and to have jumped to humans recently (9) or, when seen by others (14), to be an

ancient lineage that evolved in a remote human population (e.g., possibly the Khoisan) (14). This ins480 sequence was not found in any of the nine Gambian strains (none of which are outliers). Taken together, our PCR tests indicated that African (especially West African) *H. pylori* strains are unusual in often containing the ins180 sequence. This sequence was also more common in Spanish than in Lithuanian or other Eurasian strains tested ($P < 0.001$).

Sequence analysis of ins180 and ins480. Amplicons that putatively contained ins180 from one North American strain (B166) and one South African strain (Afr82) were sequenced. The *jhp0152-jhp0153* intergenic regions of these strains were 90 to 95% identical to that of *H. pylori* strain J99 (GenBank accession numbers AY731182 and AY731183), indicating that the larger (530-bp) amplicons from North American and African strains do indeed reflect presence of the same 180-bp insertion. These ins180 elements seemed to be inserted at the same site as that occupied by ins180 in strain J99 (just downstream of the translation stop of *hp0167*) and contained a potential 41-codon open reading frame, which may not, however, be an authentic coding region, because it lacks a consensus Shine-Dalgarno sequence and would start translation with a UUG codon.

As noted above, 4 of 20 South African strains (each of an unusual outlier group) carried a 0.5-kb insertion between

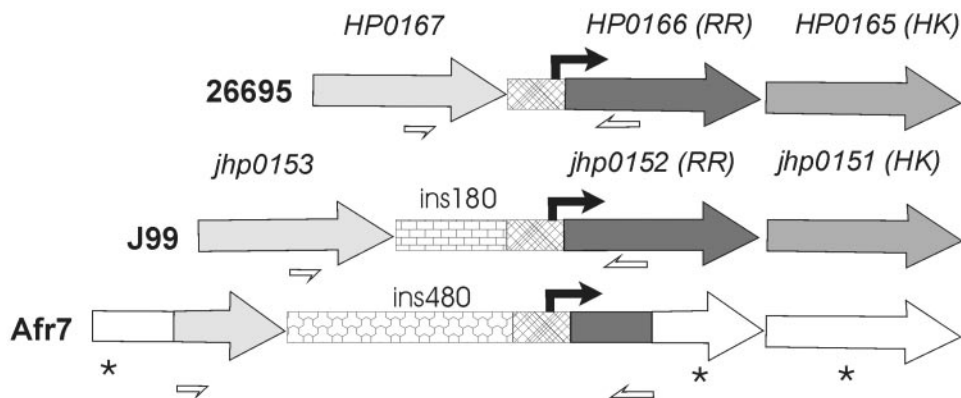


FIG. 2. Sequence comparison of response regulator promoter regions from *H. pylori* strains 26695, J99, and Afr7. Matched shadings denote sequence similarities of predicted coding regions, and patterned regions illustrate extragenic sequence homology. Asterisks indicate unsequenced regions where nucleotide homology is unknown. Black arrows indicate transcription start points for the response regulator (RR)-histidine kinase (HK) operon that was previously determined in *H. pylori* strain 26695 (10, 17). Predicted transcription start points in *H. pylori* strains Afr7 and J99 are based upon sequence homology with the orthologous region in strain 26695. White half-arrows represent binding sites for primers insFwd and insRev. The amplicon without ins180 is 350 bp, and amplicons with ins180 and ins480 are ~530 and ~830 bp long, respectively.

jhp0153 and *jhp0152* that was not found in any of the strains from other regions than that of strain Afr7, revealed an insertion of a unique 480-bp segment in this strain's intergenic region, at the same site as ins180 (Fig. 2) (GenBank accession number AY669071). This ins480 segment is not found in either of the fully sequenced genomes (strain 26695 or J99), although an ~80-bp internal sequence exhibits 70% identity with a segment of ins180 (data not shown). A search for open reading frames in ins480 revealed several small (160- to 190-bp) possible open reading frames with no significant DNA or protein-level homology to other current database entries.

ins180 is more frequent in *H. pylori* isolates from African Americans than in those from Caucasian Americans. Given the presence of ins180 in each of our nine West African strains and also its presence in nearly half of the South African strains, we tested for this or other characteristic segments in this region in *H. pylori* from infected African-American patients, relative to isolates from age- and gender-matched Caucasian-American patients ($n = 18$ in each group). Thirteen of 36 (36%) strains yielded amplicons of approximately 530 bp, indicating the presence of ins180, whereas the other 23 (64%) yielded amplicons of 350 bp, indicating a simple empty site (Fig. 3 and Table 1). According to sorting of these data by patient ethnic-

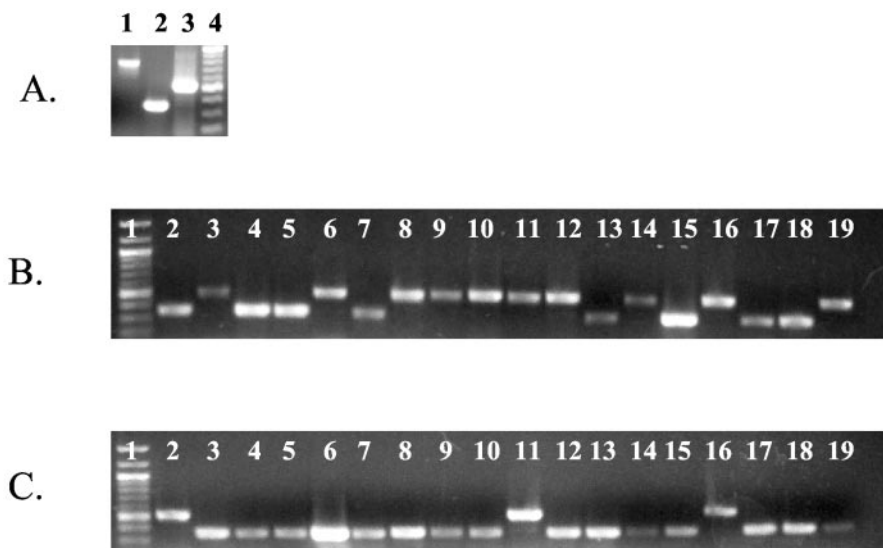


FIG. 3. ins180 is more frequent among *H. pylori* isolates from African Americans than from Caucasians. A PCR survey for ins180 in the response regulator *jhp0152* promoter region from 36 *H. pylori* strains from both African Americans ($n = 18$) and Caucasians ($n = 18$) was performed. The *jhp0153-jhp0152* intergenic region amplicon without ins180 is ~350 bp, while the amplicons possessing ins180 are 530 bp. Intergenic regions possessing ins480 yield amplicons of ~830 bp. (A) Lane 1, *H. pylori* strain Afr7 (containing ins480); lane 2, strain 26695 (no ins180 or ins480); lane 3, strain J99 (containing ins180); lane 4, 100-bp ladder. (B and C) *H. pylori* strains derived from 18 African Americans and 18 U.S. Caucasians, respectively.

ity, 10 of 18 (56%) strains from African Americans versus 3 of 18 (17%) strains from other patients carried ins180 ($P < 0.05$) (Fig. 3B and C and Table 1). There was no correlation between the presence or absence of ins180 and carriage of the *cag* PAI or patient disease outcome (data not shown).

DISCUSSION

We identified a 180-bp segment (ins180) in the promoter region of *jhp0152* in *H. pylori* strain J99 that is absent from the corresponding locus of strain 26695. These two strains, both from Caucasian males, are closely matched in DNA sequences flanking the ins180 site, which suggested that this element might be a useful marker for distinguishing different types of strains. In addition, *jhp0152* and the downstream *jhp0151* genes are coexpressed from a single promoter (10, 17), and ins180 is approximately 125 bp upstream of the transcriptional start site of *jhp0152*. We hypothesize that ins180 may introduce or disrupt a *cis*-acting sequence that affects downstream gene transcription. Since the external stimulus to which *jhp0152* and *jhp0151* (which encode components of a two-component signal transduction system) respond is likely to be a pH-dependent signal (35), it is interesting that ins180 might affect *H. pylori* colonization or persistence in its special gastric environment. Alternatively, the placement of these elements immediately downstream of the stop codon of *jhp0153*, which encodes a conserved *H. pylori*-specific protein of unknown function, raises the possibility of effects on posttranscriptional regulation of this gene. Sequences in 3' untranslated regions can have profound effects on expression of the upstream gene ("retro-regulation") by affecting access to RNases and thereby mRNA stability (21, 30).

A BLAST search with the ins180 sequence identified conserved subsequences at 5 and 13 other sites in the genomes of the two sequenced *H. pylori* strains. Others have reported that ~78% of the *H. pylori* genome was well conserved in a set of 15 strains (37). This represents ~1,300 genes, most specifying metabolic and cellular functions. Many of the other nonconserved genes encoded DNA restriction and modification enzymes, transposases, and cell surface proteins (37). *H. pylori* strains also exhibit marked differences in gene arrangement (mostly due to inversion) and extensive point mutation (1, 19). Given the repetitive nature of ins180 and related sequences, we suggest that these elements constitute substrates for homologous recombination, which occurs readily in short repetitive sequences in *H. pylori* (4).

The ins180 sequence was nonrandomly distributed geographically (Table 1). Each of nine strains from The Gambia in West Africa, nearly half of South African strains, and one-fourth of Spanish strains contained ins180, whereas only a few of the other isolates that we first surveyed (all North American) carried this element. Also of note was the larger ins480 element, which was inserted at the same site and was found in an additional 4 of 29 South African strains (14%). Each of these four was of an unusual outgroup that is distinct from mainstream *H. pylori* strains of Africa or other continents (9; Dailide and Berg, unpublished). Reinforcing the view that such polymorphisms can be useful in identifying geographic origins of different *H. pylori* strains, 10 of 18 *H. pylori* isolates from African-American patients but only 3 of another 18 isolates

from a matched Caucasian-American patient cohort carried this ins180 sequence. This is interpreted as reflecting *H. pylori*'s predominately intrafamilial transmission (3, 24, 36, 40) but is still most remarkable, given the multiple generations since the ancestors of most African Americans were taken from their West African homelands. In this context, it is tempting to imagine that ins180 in nearly one-fourth of Spanish strains might stem from the Moorish conquest and other movements of peoples between northwest Africa and the Iberian Peninsula (16).

The population correlations seen with ins180, in particular, make it attractive to consider that phylogenetic analyses of other loci in *H. pylori* strains from African Americans will also show evidence of West African origins. This may allow us to more clearly focus on bacterial versus other factors that contribute to the higher risk of gastric cancer in African Americans than in Africans. More generally, we suggest that easily scored markers such as ins180 and ins480 will be particularly useful in deciphering bacterial genetic versus other causes of particular disease associations, as epitomized by the African Enigma.

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