Helicobacter pylori is the key pathogen for gastroduodenal diseases. The clinical outcome of H. pylori infection is influenced by the presence of strain-specific virulence factors that are usually detected by the presence of specific anti-\textit{H. pylori} antibodies in serum. Apart from the detection of these antibodies by enzyme-linked immunosorbent assay (ELISA), it is desirable to obtain additional information concerning the presence of certain virulence factors of \textit{H. pylori} that are currently detected by immunoblot analysis. At present, the immunodiagnosis of an \textit{H. pylori} infection includes two separate methods: ELISA and immunoblot analysis. Here, we report the development and evaluation of a new rapid flow microparticle immunofluorescence assay (FMIA) for detection of anti-\textit{H. pylori} antibodies in human serum. The assay allows rapid qualitative and quantitative detection of anti-\textit{H. pylori} antibodies by using crude antigen preparations as well as single recombinant antigens (urease A, urease B, CagA, and alkylhydroxy peroxide reductase) in the same sample with one measurement, and thus it combines the advantages of enzyme immunoassay and Western blot analysis. Seventy-five patient samples were analyzed by FMIA, ELISA, and Western blotting with respect to their immunoreactivity against crude \textit{H. pylori} extracts and individual \textit{H. pylori} antigens. Statistical analyses revealed an overall similarity of more than 90% among the results for FMIA, ELISA, and Western blot. Therefore, we conclude that FMIA is a powerful and time- and cost-saving assay system for the detection of antimicrobial antibodies, with higher sensitivity and a larger measurement range than ELISA.
TABLE 1. Primer sequences used for cloning and expression of H. pylori antigens

<table>
<thead>
<tr>
<th>Antigen</th>
<th>Primer direction</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urease A</td>
<td>Forward</td>
<td>5′-GGAAATCCATATGAAAATCTCACCCTCCAAAGGTAGTAGGAC 5′-GGAAATCCATATGTTAATGCTTAAATTG</td>
</tr>
<tr>
<td>Urease B</td>
<td>Reverse</td>
<td>5′-GGAAATCCATATGAAAAGTTAGCAGAAAAAGATATG       5′-GGAAATCCATATGCTAAAATGCTTACATAG</td>
</tr>
<tr>
<td>CagA</td>
<td>Forward</td>
<td>5′-CATATGACTAAGACAAAAATYGMWCAA                5′-CATATGTTAAGATTTGGAAGCCAC</td>
</tr>
<tr>
<td>APR</td>
<td>Reverse</td>
<td>5′-GGAAATCCATATGTTAGTACAAAACTTGGCCACAGC       5′-GGAAATCCATATGTTAAGCTATAGGGAATTTCTTGG</td>
</tr>
</tbody>
</table>

**MATERIALS AND METHODS**

**Patients.** Seventy-five patients with dyspepsia who presented at the Department of Gastroenterology were included in the study. None of these patients had received nonsteroidal anti-inflammatory drugs or proton pump inhibitors before blood was taken. Patients were included after giving their written informed consent. The *H. pylori* status of patients was analyzed by ELISA (Pyloriset EIA-G III; BAG GmbH, Lich, Germany). Sera were initially aliquoted and stored at −30°C until use. During the study, samples were subjected to two to three freeze-thaw cycles.

**Generation of recombinant** *H. pylori* **antigens.** Clinical isolates of *H. pylori* were cultured under microaerophilic conditions at 37°C in brucella broth (Difco Laboratories; Detroit, Mich.) for 4 days. Bacteria were centrifuged at 6,000 × g at 4°C and resuspended in phosphate-buffered saline (PBS) or 0.1 M borate buffer (pH 8.5). Suspensions were sonicated on ice and centrifuged at 10,000 × g for 10 min. The protein concentration of the retained supernatants was measured with the Micro-BCA (bicinchoninic acid) assay (Bio-Rad, Munich, Germany).

**Histological detection of** *H. pylori** infection.** For histology, paraffin-embedded step sections were stained with hematoxylin and eosin to grade gastritis according to the updated Sydney system (4) and with Warthin-Starry-Silver stain to detect *H. pylori*. Histological evaluation was performed by an experienced gastrointestinal pathologist (M.V.) who was not aware of clinical history or symptoms.

**Detection of** *H. pylori** antibodies by using commercial assay systems.** Sera were analyzed with a commercially available ELISA system (Pyloriset EIA-G III) and two Western blot assays obtained from Viramed (Munich, Germany) and Biosenso (Oberhaching, Germany), referred to as Blot 1 and Blot 2, respectively. All procedures were performed according to the manufacturers’ instructions. Unless indicated otherwise, serum probes were diluted 1:75 or 1:100 for Western blots and 1:200 for ELISA.

In the ELISA, microtiter wells were coated with inactivated *H. pylori* antigen extracts and used for qualitative and quantitative antibody testing. The results were expressed in arbitrary enzyme units (EU) per milliliter of serum. They were considered positive if the number of *H. pylori* antibodies was equal to or above that of a calibrator serum (20 EU/ml), which was part of the assay system. Probes with values lower than 20 EU/ml were negative.

In both Western blot systems, defined isolates of several *H. pylori* strains were separated by SDS-PAGE and blotted on nitrocellulose membranes. The antigen preparations contained the following strain-specific proteins: CagA, VacA, 30-kDa protein, UreA, UreB, heat shock protein, and flagellin (Fig. 1A). The immunoreactions of individual patient sera were analyzed visually. They were classified as positive or negative when compared with the reference strips.

The results obtained by using Blot 1 were compared with those of Blot 2, which contained similar antigens (Fig. 1A) and was performed and evaluated as described above.

**Microparticle assay.** Nonfluorescent paramagnetic polystyrene microparticles (Kisker GmbH, Mülheim, Germany) with diameters of 6.5, 8, 10, and 12 μm and containing functional carboxylic groups were used. When indicated, fluorescein isothiocyanate (FITC)-labeled microparticles (8 μm) were used. Each microparticle population was covalently coated with either *H. pylori* antigen extract or a distinct recombinant antigen by using the carbodiimide kit for carboxylated microparticles (Polysciences, Inc., Warrington, Pa.). Different antigen concentrations were used for determination of optimal coating conditions, taking into consideration the amount of bound antigen and the homogeneity of coating. A concentration of 400 μg of antigen per ml was chosen for the coating of a 2.5% microparticle suspension.

Histological examination was performed with a Promega MagneSphere 96 rack in PBS-1% BSA-0.1% Tween 20. The immunoreaction was detected with phycoerythrin-conjugated antihuman IgG (heavy and light chains) serum (Dianova). Flow cytometric analyses were carried out with a FACSCalibur flow cytometer (BD, Heidelberg, Germany), equipped with an argon laser operating at 488 nm.
arbitrary fluorescence units (FU). Nonhomogeneous staining resulting in a skewed fluorescence distribution was found in single patient samples and did not result in significant differences between peak channels and mean fluorescence intensities.

Cutoff values for each antigen-microparticle population were calculated from the fluorescence intensities measured from a pool of at least 10 negative samples (according to commercial test systems). The cutoff value was calculated by the following formula: cutoff fluorescence intensity = mean fluorescence intensity of negative samples + (3 × standard deviation).

Statistical evaluation. All statistical analyses were performed with SPSS 10.0 for Windows (SPSS, Chicago, Ill.). Bivariate correlation coefficients were calculated according to Pearson.

RESULTS AND DISCUSSION

Characterization of recombinant proteins. Cloned H. pylori antigen DNA sequences in the pET-14b vector were expressed in E. coli cells. Figure 1B shows purified recombinant antigens from the soluble fraction in SDS-PAGE and Western blot reactions. UreA, UreB, and APR protein were produced as full-length 26-, 66-, and 22-kDa recombinant proteins. CagA was produced as an N-terminal 50-kDa fragment of the 128-kDa protein. The fragment contained all epitopes that are
recognized by the majority of naturally occurring antibodies (5). The levels of expression were 5 to 25 mg of protein per liter of culture medium.

Characterization of the microparticle assay. To establish an assay system that combines the diagnostic value of ELISA and Western blotting, microparticle populations were coated with either crude \textit{H. pylori} extracts or purified recombinant antigens. Then the populations were mixed in equal amounts and incubated with patient sera and phycoerythrin-labeled anti-human IgG. The immunoreactivity of single microparticles was measured by flow cytometry (Fig. 2). Populations coated with various proteins were differentiated according to their size (forward scatter) and their fluorescence in the green channel. Thus, five populations were gated (12 \mu m, R5; 10 \mu m, R4; 8 \mu m [with FITC], R3; 8 \mu m, R2; and 6.5 \mu m, R1). The immunoreactivity mediated by anti-\textit{H. pylori} antibodies in the patient sera correlated with the mean fluorescence intensity in the red channel.

Comparative evaluation of microparticle assay, ELISA, and histology. A large measurement range is important for sensitive and accurate detection of high and low antibody concentrations at a given dilution. Therefore, the measurement range of FMIA was compared with that of the ELISA. Patient sera were diluted between 20- and 100,000-fold and incubated either with coated microparticles or in the ELISA plates. For the crude \textit{H. pylori} antigen preparation, the measurement range of the FMIA was between dilutions of 100- and 64,000-fold, whereas the measurement range of the ELISA was between dilutions of 25- and 500-fold (Fig. 3). Thus, the FMIA was characterized by a higher sensitivity and larger measurement range.

A 1,000-fold serum dilution was used for further FMIA measurements, and a 200-fold dilution was used for ELISA. These serum dilutions were shown to be in the linear measurement range of the respective assays.

Furthermore, corresponding mean fluorescence intensities derived from the measurement of the \textit{H. pylori}-coated microparticle population were correlated to the enzyme units derived from ELISA (Fig. 4). The values derived from positive sera showed a significant bivariant correlation ($r = 0.8, P < 0.01$).

The cutoff value (300 FU) of the FMIA was calculated as described in Materials and Methods. The cutoff value for the ELISA (20 EU) was given by the manufacturer (10). All samples below 13 EU were negative in FMIA. Only some of the samples with values between 14 and 19 EU were negative in FMIA (44\%, 180 to 280 FU); most of these samples, however, were above the threshold calculated for FMIA (56\%, 400 to 1,000 FU). All ELISA-positive samples (>20 EU, ranges of 20 to 900 EU) were classified as positive in FMIA (400 to 8,000 FU) (Fig. 4). Remarkably, the microparticle assay showed a wider range of mean values than the ELISA. In particular, the discrimination of samples at the borderline between positive and negative values was better in the microparticle assay than in the ELA (14 to 19 EU versus 180 to 1,000 FU). All samples with controversial results in ELISA and FMIA were investigated by Western blotting to analyze whether the immunoreactivities detected in FMIA were specifically related to distinct \textit{H. pylori} antigens. We found that all samples that were positive in FMIA showed distinct bands in the Western blot for either UreB or CagA. From this, we concluded that the FMIA is more sensitive than the ELISA system.

Alternatively, the agreement of qualitative results between
ELISA and FMIA could be increased above 90% if the cutoff value of FMIA was increased empirically to 700 FU.

Furthermore, the FMIA and the ELISA results were compared to histological findings derived from gastric biopsy samples (Fig. 4B and C). We found that samples from all patients with positive histology were positive in FMIA and ELISA. This corresponds to the high sensitivity of both methods. On the other hand, in sera of some patients that were negative in histology, we found anti-

H. pylori antibodies in FMIA and ELISA (51 and 30%, respectively). Considering also the detection of specific bands in the Western blot, we suggest that these differences between histology and FMIA or ELISA support the lower specificity of all three methods (1). Again, the number of false-positive samples in FMIA could be decreased to a number similar to that of the ELISA by increasing the cutoff value to 700 FU.

Comparative evaluation of the microparticle assay and Western blot. Mean fluorescence intensities derived from the measurement of beads, which were coated with single recombinant H. pylori antigens, were correlated to the semiquantitative evaluation of the Western blots (Fig. 5). FMIA results of UreA-coated beads showed an agreement rate of 87% with those derived from Blot 1. Five percent of the samples were false positive and 8% were false negative in the FMIA compared to Western blot. Immunoreactivities for UreB showed similar results: an agreement of 87%, a false-positive identification of 4%, and a false-negative identification of 10%. The highest correlation was found for CagA, with an agreement of 90% between the microparticle assay and Blot 1, whereas 6% were false positive and 4% were false negative. The lowest correlation was found for APR with 66% agreement (4% false positive and 30% false negative).

To analyze whether these differences between FMIA and blot 1 were related to the detection systems or to antigen preparations, we compared Western blots from different manufacturers. As shown in Fig. 6, the correlation between Western blots obtained from different manufacturers was similar to that of FMIA and Blot 1. Again, we found agreement rates between 87 and 90% for all antigens investigated, except APR. Thus, the differences may result from variations in the H. pylori
strains used for antigen preparation, the amounts of antigen used for coating of the microparticles, or the antigen preparation methods. In addition, the Western blots were sometimes difficult to evaluate because of faint bands.

Since the highest variation was found in the antibodies directed against the APR protein, we speculated that different strains used for antigen preparation, the amounts of antigen used for coating of the microparticles, or the antigen preparation methods. In addition, the Western blots were sometimes difficult to evaluate because of faint bands.

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Seroprevalence of antibodies against defined H. pylori antigens. Recombinant H. pylori antigens were used to evaluate the specificity of antibodies in patient sera. We tested whether it was possible to assign a specific immunoreactivity to each serum that stained the microparticles coupled to the crude H. pylori extract. The highest seroprevalence was found for anti-UreA, anti-UreB, and anti-CagA antibodies. All samples from seropositive patients, retrieved in the assay using H. pylori extract, contained antibodies against either UreA or UreB; about 30% of the positive sera contained antibodies against both urease isoforms. CagA antibodies were found in 68% of the seropositive samples, while anti-APR antibodies were found only in 17% according to the microparticle assay and 43 or 67% of the patient sera according to the blot systems (Table 2).

We conclude that the recombinant antigens UreA, UreB, and CagA, and to some extent APR, as well as H. pylori whole-cell lysate, are useful antigens in microparticle assays for the detection of anti-H. pylori antibodies. Results obtained by FMIA were similar to those from commercially available ELISA and Western blot assays. Thus, FMIA indeed integrates both ELISA and Western blotting and is a time- and consequently cost-saving method for detection of antimicrobial antibodies.

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REFERENCES


