CLINICAL AND VACCINE IMMUNOLOGY, Dec. 2010, p. 1875–1880 Vol. 17, No. 12
1556-6811/10/$12.00 doi:10.1128/CVI.00278-10

Prevalence of Antibodies to Four Human Coronaviruses Is Lower in Nasal Secretions than in Serum▽

Geoffrey J. Gorse,[1,2]* Gira B. Patel,[2] Joseph N. Vitale,[3] and Theresa Z. O'Connor[3]

Department of Veterans Affairs Medical Center, St. Louis, Missouri[1]; Saint Louis University, St. Louis, Missouri[2]; and Department of Veterans Affairs Cooperative Studies Program Coordinating Center, West Haven, Connecticut[3]

Received 6 July 2010/Returned for modification 15 August 2010/Accepted 6 October 2010

Little is known about the prevalence of mucosal antibodies induced by infection with human coronaviruses (HCoV), including HCoV-229E and -OC43 and recently described strains (HCoV-NL63 and -HKU1). By enzyme-linked immunosorbent assay, we measured anti-HCoV IgG antibodies in serum and IgA antibodies in nasal wash specimens collected at seven U.S. sites from 105 adults aged 50 years and older (mean age, 67 ± 9 years) with chronic obstructive pulmonary disease. Most patients (95 [90%]) had at least one more chronic disease. More patients had serum antibody to each HCoV strain (104 [99%] had antibody to HCoV-229E, 105 [100%] had antibody to HCoV-OC43, 103 [98%] had antibody to HCoV-NL63, and 96 [91%] had antibody to HCoV-HKU1) than had antibody to each HCoV strain in nasal wash specimens (12 [11%] had antibody to HCoV-229E, 22 [22%] had antibody to HCoV-OC43, 8 [8%] had antibody to HCoV-NL63, and 31 [31%] had antibody to HCoV-HKU1), respectively ($P < 0.0001$). The proportions of subjects with IgA antibodies in nasal wash specimens and the geometric mean IgA antibody titers were statistically higher for HCoV-OC43 and -HKU1 than for HCoV-229E and -NL63. A higher proportion of patients with heart disease than not had IgA antibodies to HCoV-NL63 (6 [16%] versus 2 [3%]; $P = 0.014$). Correlations were highest for serum antibody titers between group I strains (HCoV-229E and -NL63 [$r = 0.443$; $P < 0.0001$]) and between group II strains (HCoV-OC43 and -HKU1 [$r = 0.603$; $P < 0.0001$]) and not statistically significant between HCoV-NL63 and -OC43 and between HCoV-NL63 and -HKU1. Patients likely had experienced infections with more than one HCoV strain, and IgG antibodies to these HCoV strains in serum were more likely to be detected than IgA antibodies to these HCoV strains in nasal wash specimens.

Coronaviruses comprise a genus of the family *Coronaviridae* and are enveloped, single-stranded, positive-sense RNA viruses (30). Four human coronavirus (HCoV) strains have been described, which are associated with a spectrum of disease, from mild, febrile upper respiratory tract illnesses to severe illnesses, including croup, bronchiolitis, and pneumonia, and have a wide geographic distribution (1, 2, 6, 7, 9–14, 16, 20, 25, 26, 31, 32, 35, 39–46). HCoV infection has been a contributor to severe illnesses requiring emergency care and hospitalization of patients with chronic medical conditions (7, 9, 12, 15, 16, 21, 22).

The earliest-described HCoV strains, HCoV-229E and HCoV-OC43, which are group I and group II coronaviruses, respectively, have now been joined by the more recently described group I and II strains HCoV-NL63 and HCoV-HKU1 (13, 30, 42, 45, 46), which were discovered in the search for other pathogenic coronaviruses after the identification of the coronavirus that causes severe acute respiratory syndrome (SARS) (29). HCoV-NL63 may have infected human populations for a long time, since it diverged phylogenetically from HCoV-229E about 1,000 years ago (33), and seroprevalence would likely be high as a result. Cross-sectional and longitudinal seroepidemiological studies have found large proportions of children and healthy adults to have detectable serum antibodies to the four HCoV strains, and seroconversion occurs often in childhood; seroprevalence increases with age, and reinfections may occur (5, 8, 23, 28, 36–38). More information is needed about the seroprevalence of these viruses, the durability of the humoral immune response, correlates of immunity, and mucosal antibody responses to HCoV infection. The present study questioned whether the prevalence of antibodies to the four HCoV strains would be different in nasal secretions than in serum of older adult veterans with underlying chronic obstructive pulmonary disease (COPD) who participated in Department of Veterans Affairs Cooperative Study 448 (18).

MATERIALS AND METHODS

Subjects. A convenience sample of 105 patients who met spirometric criteria for COPD and were enrolled in a larger influenza virus vaccine efficacy trial of patients ≥50 years of age (18) were chosen for analysis in this substudy of the prevalence of antibodies to HCoV, because residual serum and nasal wash specimens collected at the same time for each subject were available for analysis. The 105 subjects were enrolled at seven geographically diverse study sites in the United States, located in the following states: Alabama, Florida, Illinois, Massachusetts, Michigan, Missouri, and Texas. The paired serum and nasal wash specimens were collected at about 3 to 4 weeks following influenza virus vaccination between October 1998 and February 1999 and were not associated with acute respiratory illness at the time of collection. All patients gave written informed consent, and responsible committees on human experimentation approved of the study.

Antigen preparation and ELISA. The HCoV antigens used for the antibody enzyme-linked immunosorbent assay (ELISA) were produced as described previously (16). HCoV-229E and HCoV-OC43 were obtained from the American Type Culture Collection (ATCC, Manassas, VA) and were grown in MRC-5 and HCT-8 cell monolayers (ATCC), respectively. HCoV-NL63 was grown in LLC-MK2 cell monolayers (a gift from Lia van der Hoek, University of Amsterdam, Amsterdam, Netherlands). Virus-infected cells were frozen and thawed three times, the supernatant fluid was cleared of cell debris by centrifugation, the virus

* Corresponding author. Mailing address: Division of Infectious Diseases and Immunology, Saint Louis University School of Medicine, 1100 South Grand Boulevard, DRC-8th Floor, St. Louis, MO 63104. Phone: (314) 977-5500. Fax: (314) 771-3816. E-mail: gorsegj@slu.edu.
▽ Published ahead of print on 13 October 2010.

was concentrated by overnight centrifugation, and the virus pellet was resuspended in phosphate-buffered saline (PBS). The concentrated virus was inactivated by a psoralen compound (Sigma, St. Louis, MO), followed by irradiation by long-wavelength UV light, as described previously (34). Mock antigen was prepared, in the same way, from uninfected cells.

The His_6-tagged recombinant N protein of HCoV-HKU1 was used as an antigen in the ELISA to detect antibody to HCoV-HKU1. Expression vector pET-28b(+) (Novagen, Inc., New Canaan, CT), encoding the N protein of HCoV-HKU1 cloned into the EcoRI and NotI sites in frame and downstream from a series of six-histidine residues, as described previously (45, 46), was a gift from K. Y. Yuen (University of Hong Kong, Hong Kong). The recombinant N protein was expressed by the transformation of BL21(DE3) single competent cells (Novagen, Inc.) by the plasmid and was purified by use of the Ni^{2+}-loaded HiTrap chelating system (Amersham Biosciences, Piscataway, NJ) according to the manufacturer's instructions and as described previously (16). In brief, transformed cells were disrupted, and the protein sample was prepared by the isolation of inclusion bodies via sonication and washing. The protein sample was loaded onto the HiTrap chelating HP column prepacked with precharged high-performance Ni^{2+} Sepharose. The protein was then purified and refolded by serial buffer washes of the column and by liquid chromatography in a fast protein liquid chromatography (FPLC) system (Pharmacia LBK Biotechnology, Piscataway, NJ), with elution of protein, which was collected in fractions. The fractions were analyzed for the presence of the 53-kDa protein by SDS-PAGE. The protein concentration was determined by the Bio-Rad protein assay (Bio-Rad Laboratories, Hercules, CA) and was adjusted to 3 μg/ml for the ELISA. Mock antigen was produced from the same plasmid DNA vector, but without the N protein gene sequence, by the same procedure.

Each viral antigen and its respective control were used to coat flat-bottom 96-well Maxisorp Immunoplates (Nalge-Nunc International, Rochester, NY). To measure serum IgG antibodies, the sequence of reagents consisted of serum in a series of eight 2-fold dilutions starting at a 100-fold dilution to generate a broad dose-response curve, mouse anti-human IgG (Fc specific) conjugated with horseradish peroxidase (Accurate Chemical and Scientific, Westbury, NY), and *o*-phenylenediamine substrate (KPL, Gaithersburg, MD). The optical density (OD) was measured at 405 nm by use of a Tecan (Research Triangle Park, NC) SLT400 spectrophotometer. The anti-HCoV antibody titer in the ELISA was calculated by the reference-line least-squares-fit method. The cutoff OD was set at 0.3 for all viral antigens, a level that was at least twice the background OD for the respective mock antigens, and corresponded to the linear range of OD versus reciprocal-dilution curves.

To measure IgA antibodies in nasal wash specimens, the nasal wash specimens were first sonicated and then concentrated by using centrifugal filter devices (Centriprep; Millipore Corp., Ireland) according to the manufacturer's instructions. The concentrated nasal wash specimens were tested in an ELISA, which was the same as that used for sera, except that the nasal wash specimens were diluted in a series of six 2-fold dilutions starting at a 5-fold dilution and goat anti-human IgA (α-chain) conjugated with horseradish peroxidase (MP Biomedicals-Cappel, Solon, OH) was employed. An endpoint anti-HCoV antibody titer was the final dilution of the nasal wash specimen with an OD in the antigen-coated well of 0.3 or greater and that was at least twice that of the respective control, as described previously (17, 19). The total IgA antibody concentration in the nasal wash specimens was determined previously by ELISA (17). Briefly, the sequence of reagents beginning with the solid phase was goat anti-human IgA (ICN/Cappel Pharmaceuticals, Inc., Aurora, OH), the nasal wash specimen, goat anti-human IgA (α-chain specific) conjugated with horseradish peroxidase, and *o*-phenylenediamine substrate. The standard curve of known secretory IgA concentrations was determined by using serial dilutions of human secretory IgA (ICN Biomedical, Inc., Costa Mesa, CA) instead of nasal wash specimens in the ELISA. We repeated the measurement of total IgA concentrations in this study, finding that there was no decay in the total IgA concentration in these specimens that were stored at −70°C for about 9 years after their initial collection. The anti-HCoV IgA antibody titer in nasal wash specimens was mathematically adjusted to an arbitrary total IgA antibody concentration of 100 mg/liter using the measured total IgA antibody concentration for each specimen.

Statistical methods. Demographic and antibody data were analyzed by using descriptive statistics. Reciprocal antibody titers were logarithmically transformed, and geometric mean titers (GMTs) were compared by using the Wilcoxon signed-rank test. McNemar's test was used to compare pairwise proportions of subjects with detectable anti-HCoV antibodies. Nonpaired data were compared by using the χ^2 test or Fisher's exact test and the Wilcoxon rank sum test. Logarithmically transformed serum IgG antibody titers against HCoV strains were assessed by linear regression, and Pearson correlations were performed.

TABLE 1. Demographics and clinical characteristics of the study subjects

Characteristic	Value
No. of subjects	105
No. (%) of male subjects	101 (96)
Mean age (yr) ± SD (range)	67 ± 9 (50–82)
No. (%) of subjects 50–64 yr of age	37 (35)
No. (%) of subjects ≥65 yr of age	68 (65)
No. (%) of white subjects	97 (92)
No. (%) of current tobacco smokers	37 (35)
Mean FEV_1/FVC ratio ± SD[a]	0.52 ± 0.13
Mean % predicted FEV_1 ± SD[a]	41.5 ± 15
No. (%) of subjects with history of diseases other than COPD	
One or more diseases	95 (90)
Heart disease	37 (35)
Diabetes mellitus	17 (16)

[a] Spirometric criteria for COPD were an FEV_1 that was 80% or less of the predicted value and an FEV_1/FVC ratio of less than 0.70, as described previously (18), where FEV_1 is the forced expiratory volume in 1 s and FVC is the forced vital capacity.

RESULTS

Of the 105 patients studied, 101 (96%) were male and 97 (92%) were white (Table 1). All had spirometrically confirmed obstructive pulmonary disease, 95 (90%) had one or more additional underlying illnesses, and 68 (65%) were 65 years of age or older (Table 1).

At least 98% of the 105 patients had serum IgG antibodies to HCoV-229E, -NL63, and -OC43, while 96 (91%) had serum IgG antibody to HCoV-HKU1 (Table 2). The proportions of patients with detectable IgG antibodies to HCoV-229E, -NL63, and -OC43 were all greater than the proportion with IgG antibody to HCoV-HKU1 ($P = 0.011$, $P = 0.035$, and $P = 0.0004$, respectively). Compared to serum IgG antibody, smaller proportions of patients had IgA antibody to each of the HCoV strains in nasal wash specimens (12 [11%] were HCoV-229E positive, 8 [8%] were HCoV-NL63 positive, 22 [22%] were HCoV-OC43 positive, and 31 [31%] were HCoV-HKU1 positive) ($P < 0.0001$) (Table 2). The proportions of patients with IgA antibodies against HCoV-OC43 and -HKU1 were significantly greater than those with IgA antibodies against HCoV-229E ($P = 0.03$ and $P = 0.0013$, respectively) and HCoV-NL63 ($P = 0.001$ and $P < 0.0001$, respectively) (Table 2). Anti-HCoV IgA antibody GMTs for nasal wash specimens with detectable antibody were within a 2-fold dilution range when the four viral strains were compared (Table 2). The GMTs were higher and the ranges of individual IgA antibody titers included higher values for HCoV-OC43 and -HKU1 than HCoV-229E ($P = 0.003$ and $P = 0.0006$, respectively) and -NL63 (both $P < 0.0001$). The serum IgG antibody GMT for HCoV-229E was less than that for HCoV-OC43 ($P = 0.003$), and the serum IgG GMTs for HCoV-229E and -OC43 were each greater than those for HCoV-NL63 and -HKU1 ($P < 0.0001$). The serum IgG antibody GMTs for HCoV-229E and -OC43 were about 2-fold higher than those for HCoV-NL63 and -HKU1.

The ranges of individual IgG antibody titers extended more than 7-fold higher for HCoV-229E over HCoV-NL63 and 5-fold higher for HCoV-OC43 over HCoV-HKU1 (Table 2), but only 11 sera had an IgG antibody titer against HCoV-229E

TABLE 2. IgG antibodies to HCoV in serum and IgA antibodies to HCoV in nasal wash specimens

Strain	IgG antibody to HCoV in serum					IgA antibody to HCoV in NW specimens				
	No. of positive samples (%)/ total no. of samples tested	GMT of all sera[a]	Only sera with detectable antibody			No. of positive samples (%)/ total no. of samples tested[b]	GMT of all NW specimens[a]	Only NW specimens with detectable antibody		
			GMT	Median	Range			GMT	Median	Range
Group I										
HCoV-229E	104 (99)/105[c]	994[d]	1,022	1,038	127–23,706	12 (11)/105[f]	3.6[h]	59	62	19–147
HCoV-NL63	103 (98)/105[c]	567[d,e]	595	629	109–3,095	8 (8)/105[g]	3.2[i]	55	57	27–116
Group II										
HCoV-OC43	105 (100)/105[c]	1,235[d,e]	1,235	1,137	127–45,816	22 (22)/102[f,g]	5.3[h,i]	92	100	29–691
HCoV-HKU1	96 (91)/105[c]	466[d,e]	575	527	106–8,392	31 (31)/101[f,g]	6.6[h,i]	66	58	20–447

[a] GMT, geometric mean titer, calculated by the inclusion of all specimens. Sera without detectable antibody titers against HCoV were arbitrarily assigned a titer of 50, and nasal wash (NW) specimens without detectable antibody titers against HCoV were arbitrarily assigned a titer of 2.5.

[b] Four specimens were depleted prior to the finishing of testing against all viral antigens.

[c] There was significant nonagreement between antibody pairs against HCoV-229E and HCoV-HKU1, between HCoV-NL63 and HCoV-HKU1, and between HCoV-0C43 and HCoV-HKU1 ($P = 0.011$, $P = 0.035$, and $P = 0.004$, respectively, by McNemar's test). The proportion with serum IgG antibody was different than the proportion with IgA antibody in nasal wash specimens for each HCoV strain, respectively ($P < 0.0001$).

[d] The GMT against HCoV-229E was greater than the GMT against HCoV-NL63 and HCoV-HKU1 ($P < 0.0001$ by Wilcoxon signed-rank test). The GMT against HCoV-229E was less than the GMT against HCoV-OC43 ($P = 0.003$ by Wilcoxon signed-rank test).

[e] The GMT against HCoV-OC43 was greater than the GMTs against HCoV-NL63 and HCoV-KHU1 ($P < 0.0001$ by Wilcoxon signed-rank test).

[f] There was significant nonagreement between antibody pairs against HCoV-229E and HCoV-OC43 and between antibody pairs against HCoV-229E and HCoV-HKU1 ($P = 0.03$ and $P = 0.0013$, respectively, by McNemar's test).

[g] There was significant nonagreement between antibody pairs against HCoV-NL63 and HCoV-OC43 and between antibody pairs against HCoV-NL63 and HCoV-HKU1 ($P = 0.001$ and $P < 0.0001$, respectively, by McNemar's test).

[h] The GMT against HCoV-229E was less than the GMT against HCoV-OC43 and HCoV-HKU1 ($P = 0.003$ and $P = 0.0006$, respectively, by Wilcoxon signed-rank test).

[i] The GMT against HCoV-NL63 was less than the GMTs against HCoV-OC43 and HCoV-HKU1 ($P < 0.0001$ by Wilcoxon signed-rank test).

that was greater than the highest titer against HCoV-NL63, and only 2 sera had an IgG antibody titer against HCoV-OC43 that was greater than the highest titer against HCoV-HKU1. Between 13% and 75% of nasal wash specimens with IgA antibody to one HCoV strain had antibody to another viral strain (Table 3). Five nasal wash specimens had titers of IgA antibody to HCoV-OC43 that exceeded the highest titer against HCoV-229E in any specimen, and none of these five specimens had detectable antibody to HCoV-229E. Similarly, seven nasal wash specimens had IgA antibody titers against HCoV-HKU1 that exceeded the highest titer against HCoV-NL63 in any specimen, and only one of these seven specimens had antibody to HCoV-NL63. Hence, the cross-reactive IgA antibodies to more than one viral strain that might be expected for high-titer specimens were often not present for a strain in the other HCoV group.

TABLE 3. Concomitant detection of IgA antibodies to one or more strains of HCoV in nasal wash specimens

Nasal wash specimen with detectable IgA antibodies to the HCoV strain (no. positive)	No. (%) of nasal wash specimens with concomitantly detectable IgA antibodies to another HCoV strain			
	Group I		Group II	
	HCoV-229E	HCoV-NL63	HCoV-OC43	HCoV-HKU1
Group I				
HCoV-229E (12)		4 (33)	7 (58)	4 (33)
HCoV-NL63 (8)	4 (50)		6 (75)	5 (63)
Group II				
HCoV-OC43 (22)	7 (32)	6 (27)		12 (55)
HCoV-HKU1 (31)	4 (13)	5 (16)	12 (39)	

Since most sera had IgG antibodies to all four HCoV strains, we assessed correlations between serum IgG antibody titers against HCoV strains to characterize possible antigenic relationships between HCoV strains and groups based on seroreactivity. The highest levels of correlation were between strains within each of HCoV group I (Fig. 1A) and group II (Fig. 1B). Comparisons of serum IgG antibody titers against HCoV strains between groups had lower correlation coefficients that were either not statistically significant or at weaker significance levels (Fig. 1C to F) than those observed for the within-group comparisons (Fig. 1A and B). Thus, these data are also consistent with patients having experienced infections with both group I and group II HCoV strains in the past.

Serum IgG and nasal wash specimen IgA antibody GMTs against each HCoV strain were not significantly different when current smokers were compared to nonsmokers and when patients with a history of heart disease were compared to those without a history of heart disease (data not shown). The proportions of patients with nasal wash specimen IgA antibodies to the HCoV strains who were current smokers compared to nonsmokers did not differ significantly (data not shown). The proportion with IgA antibodies to HCoV-NL63 in nasal wash specimens of patients with a history of heart disease was higher than that of patients without heart disease (6 [16%] versus 2 [3%]; $P = 0.014$), but the proportions with IgA antibodies to the other three HCoV strains in nasal wash specimens from patients with and those without heart disease did not differ (data not shown).

DISCUSSION

Serum IgG antibodies to all four HCoV strains were present in most study subjects, but IgA antibodies to the four HCoV strains were detected less frequently in nasal wash specimens,

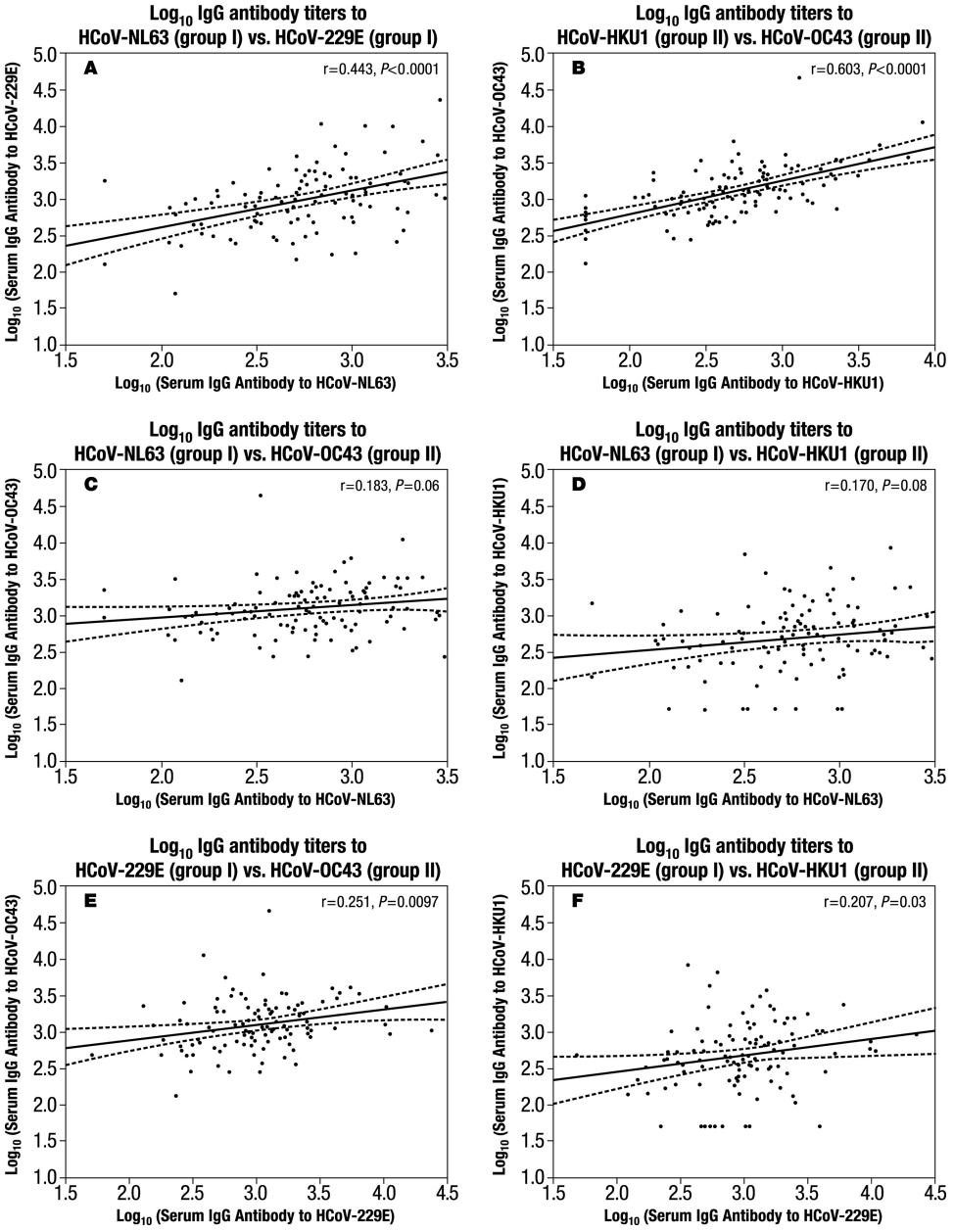

FIG. 1. Log_{10}-transformed serum IgG antibody titers in scatter plots, with solid dots representing data points, solid lines representing the linear regression best-fit line through the data points, and the dashed, curvilinear lines representing the 95% confidence limits for mean predicted values. Sera without detectable antibody at a dilution of 1:100 are shown as an arbitrary titer of 50 (log_{10} transformed). The log-transformed data were normally distributed, and Pearson correlations were performed. (A) Log_{10} IgG antibody titers against HCoV-NL63 versus HCoV-229E ($r = 0.443$; $P < 0.0001$). (B) Log_{10} IgG antibody titers against HCoV-HKU1 versus HCoV-OC43 ($r = 0.603$; $P < 0.0001$). (C) Log_{10} IgG antibody titers against HCoV-NL63 versus HCoV-OC43 ($r = 0.183$; $P = 0.06$). (D) Log_{10} IgG antibody titers against HCoV-NL63 versus HCoV-HKU1 ($r = 0.170$; $P = 0.08$). (E) Log_{10} IgG antibody titers against HCoV-229E versus HCoV-OC43 ($r = 0.251$; $P = 0.0097$). (F) Log_{10} IgG antibody titers against HCoV-229E versus HCoV-HKU1 ($r = 0.207$; $P = 0.03$).

for only 8% to 31% of subjects. Patients represented a broad geographic distribution, from the Midwestern, Southern, and Northeastern regions of the United States. A wide range of IgG and IgA antibody titers against HCoV was observed. The levels of mean IgG antibody to HCoV-229E and -OC43 were higher than levels of mean IgG antibody to HCoV-NL63 and -HKU1, respectively. Nasal wash specimen IgA antibodies to the two group II HCoV strains were more frequently detected than were antibodies to the two group I strains, and the mean antibody titers were higher for the group II strains as well. Since the mean antibody titers against the HCoV strains in serum and also in nasal wash specimens were within about a 2-fold range, it is unclear if the statistical differences in mean titers are important clinically. The concomitant presence of

IgA antibody to more than one HCoV strain was observed for some nasal wash specimens but was universal in the case of serum IgG antibody to HCoV.

The findings may reflect previous infections of patients with more than one viral strain, antibody cross-reactivity between strains due to HCoV group-specific rather than strain-specific antigens, better induction of mucosal IgA antibodies by certain HCoV strains and a shorter period of detectability after infection in secretions than in serum, and a better preservation of antibodies in the nasal wash specimens with antibody to HCoV than in those that had no detectable anti-HCoV antibody despite similar storage conditions. However, the amount of total IgA in the specimens did not decline during storage, so strain-specific IgA antibodies should not have decayed in storage either. Correlation of serum IgG antibody titers within and across HCoV groups showed a more striking association between the levels of antibody to the HCoV strains within each group than across groups. This may reflect antigenic cross-reactivity within HCoV groups but less so between groups. Also, cross-reactive IgA antibodies to HCoV strains between HCoV groups were generally not observed in high-titer nasal wash specimens.

Levels of serum antibody to HCoV-229E and -OC43 in our study in terms of GMT and the frequency of detection were similar to data reported previously by Schmidt et al. (36), who described repeated significant increases in antibody longitudinally over time, suggesting that reinfections occurred with the same virus strain. The prevalence of serum antibodies to HCoV-229E and -OC43 in our study was higher than those reported previously by Hruskova et al. (23) in Czechoslovakia and was higher than the prevalence of serum antibodies to HCoV-229E in children and adolescents in the United States reported previously by Shao et al. (38) but was similar to those reported for HCoV-OC43 in health care workers in France (28). Children in the Netherlands aged 2.5 to 3.5 years had serum antibodies to HCoV-NL63 and HCoV-229E in 75% and 65% of serum samples collected cross-sectionally, respectively (8). Severance et al. (37) previously reported seroprevalence rates of about 90% for HCoV-229E, -NL63, and -OC43 among a largely adult population in Maryland but a seroprevalence rate of only 59% for HCoV-HKU1, which is lower than that reported in the present study. In seroepidemiological studies of families including children and young adults in one community, a high prevalence of antibodies to HCoV-229E and -OC43 was reported, and frequent reinfections occurred despite preexisting serum antibody (27). Thus, there is evidence for infections with these viruses being common in children and adults and occurring over a wide geographical distribution and frequently over time.

We did not identify a difference in antibody titers when current smokers were compared to nonsmokers, unlike what was reported by Severance et al. (37) for IgG antibodies to HCoV-OC43. For unclear reasons, patients with a history of heart disease were more likely to have IgA antibodies to HCoV-NL63 in nasal wash specimens in our study. The receptor that HCoV-NL63 uses to find and enter target cells is unique among group I and II coronaviruses but is the same as that for SARS coronavirus. This receptor is angiotensin-converting enzyme 2 (ACE2), which is present on arterial and venous endothelial cells, arterial smooth-muscle cells, and small intestine and tracheobronchial airway epithelia (32). ACE2 helps regulate the renin-angiotensin-aldosterone system, which is activated in heart failure, by inactivating angiotensin II, and ACE2 plays a role in protection from severe acute lung injury (3, 24, 32). Among the human coronaviruses, HCoV-NL63 in particular has been associated with croup (31, 35, 43).

Two reports of IgA antibodies to HCoV in nasal secretions could be found in the literature. Callow et al. (5) reported previously that IgA antibodies to HCoV-229E were detectable in nasal wash specimens after experimental infection of adults with the virus and that the IgA antibody levels declined during follow-up but remained higher than preinfection levels 52 weeks later. Another previous report by Callow (4) suggested that HCoV-229E-specific antibodies in serum and nasal wash specimens were correlated with protection from experimental infection with HCoV-229E and disease, and IgA antibodies to HCoV-229E in nasal wash specimens were associated with a reduced duration of viral shedding in nasal secretions. Hence, despite the near-universal presence of serum antibodies to the HCoV strains in our study, the lower rates of detectable IgA antibodies to HCoV suggest a possible reason for susceptibility to reinfections with HCoV, if IgA antibodies in nasal secretions are indeed protective.

In summary, serum IgG antibodies to all four HCoV strains were detectable in most patients studied. It appears likely that patients may experience infections with more than one strain of HCoV. We did not measure IgA antibody to HCoV in serum in this study, since we were more interested in its presence in respiratory secretions, the compartment in which IgA is an important mediator of specific immunity. Based on the much lower frequency of patients with HCoV-specific IgA antibody in nasal wash specimens than of those with IgG in serum in our older adult population, one might hypothesize that antibodies to HCoV in nasal secretions decline in titer more rapidly after infection than do serum antibodies or that infection does not induce IgA antibody to HCoV in nasal secretions to high titers or at all in a significant proportion of older, chronically ill patients with COPD. Whether the induction of virus-specific, mucosal IgA antibodies by HCoV infection and their durability are different in older, chronically ill adults than in younger, healthy adults and children will require further study. Delineation of the relative importance of IgA antibodies in nasal secretions and serum IgG antibodies as immune correlates of protection against infection with HCoV and the role that antibodies that cross-react among HCoV strains may play in protection from or pathogenesis of HCoV infection would assist in devising approaches to the development of vaccines that could prevent HCoV infection.

ACKNOWLEDGMENTS

This work was supported by VA Research, the Cooperative Studies Program of the Department of Veterans Affairs Office of Research and Development (CSP448 and CSP448A); the National Institute of Allergy and Infectious Diseases, National Institutes of Health (contracts N01-AI-25464, HHSN272200800003C, and N01-AI-80003); and MedImmune Vaccines, Inc. (formerly Aviron) (funds to the Cooperative Studies Program of the Department of Veterans Affairs Office of Research and Development).

We thank Nancy Krudwig for laboratory technical assistance and Carolyn Novotny for word processing during manuscript preparation.

REFERENCES

1. **Arden, K. E., M. D. Nisssen, T. P. Sloots, and I. M. Mackay.** 2005. New human coronavirus, HCoV-NL63, associated with severe lower respiratory tract disease in Australia. J. Med. Virol. **75:**455–462.
2. **Bastien, N., K. Anderson, L. Hart, P. Van Caeseele, K. Brandt, D. Milley, T., Hatchette, E. C. Weiss, and Y. Li.** 2005. Human coronavirus NL63 infection in Canada. J. Infect. Dis. **191:**503–506.
3. **Braunwald, E.** 2005. Normal and abnormal myocardial function, p. 1358. *In* D. L. Kasper, A. S. Fauci, D. L. Longo, E. Braunwald, S. L. Hauser, and J. L. Jameson (ed.), Harrison's principles of internal medicine, 16th ed. McGraw-Hill Medical Publishing Division, New York, NY.
4. **Callow, K. A.** 1985. Effect of specific humoral immunity and some non-specific factors on resistance of volunteers to respiratory coronavirus infection. J. Hyg. (Camb.) **95:**173–189.
5. **Callow, K. A., H. F. Parry, M. Sergeant, and D. A. J. Tyrrell.** 1990. The time course of the immune response to experimental coronavirus infection of man. Epidemiol. Infect. **105:**435–446.
6. **Chiu, S. S., K. H. Chan, K. W. Chu, S. W. Kwan, Y. Guan, L. L. Poon, and J. S. Peiris.** 2005. Human coronavirus NL63 infection and other coronavirus infections in children hospitalized with acute respiratory disease in Hong Kong, China. Clin. Infect. Dis. **40:**1721–1729.
7. **Dare, R. K., A. M. Fry, M. Chittaganpitch, P. Sawanpanyalert, S. J. Olsen, and D. D. Erdman.** 2007. Human coronavirus infections in rural Thailand: a comprehensive study using real-time reverse-transcription polymerase chain reaction assays. J. Infect. Dis. **196:**1321–1328.
8. **Dijkman, R., M. F. Jebbink, N. B. El Idrissi, K. Pyrc, M. A. Mu¨ller, T. W. Kuijpers, H. L. Zaaijer, and L. van der Hoek.** 2008. Human coronavirus NL63 and 229E seroconversion in children. J. Clin. Microbiol. **46:**2368–2373.
9. **El-Sahly, H. M., R. L. Atmar, W. P. Glezen, and S. B. Greenberg.** 2000. Spectrum of clinical illness in hospitalized patients with "common cold" virus infections. Clin. Infect. Dis. **31:**96–100.
10. **Esper, F., C. Weibel, D. Ferguson, M. L. Landry, and J. S. Kahn.** 2005. Evidence of a novel human coronavirus that is associated with respiratory tract disease in infants and young children. J. Infect. Dis. **191:**492–498.
11. **Esper, F., C. Weibel, D. Ferguson, M. L. Landry, and J. S. Kahn.** 2006. Coronavirus HKU1 infection in the United States. Emerg. Infect. Dis. **12:** 775–779.
12. **Falsey, A. R., E. E. Walsh, and F. G. Hayden.** 2002. Rhinovirus and coronavirus infection-associated hospitalizations among older adults. J. Infect. Dis. **185:**1338–1341.
13. **Fouchier, R. A., N. G. Hartwig, T. M. Bestebroer, B. Niemeyer, J. C. de Jong, J. H. Simon, and A. D. Osterhaus.** 2004. A previously undescribed coronavirus associated with respiratory disease in humans. Proc. Natl. Acad. Sci. U. S. A. **101:**6212–6216.
14. **Garbino, J., S. Crespo, J. D. Aubert, T. Rochat, B. Ninet, C. Deffernez, W. Wunderli, J. C. Pache, P. M. Soccal, and L. Kaiser.** 2006. A prospective hospital-based study of the clinical impact of non-severe acute respiratory syndrome (non-SARS)-related human coronavirus infection. Clin. Infect. Dis. **43:**1009–1015.
15. **Glezen, W. P., S. B. Greenberg, R. L. Atmar, P. A. Piedra, and R. B. Couch.** 2000. Impact of respiratory virus infections on persons with chronic underlying conditions. JAMA **283:**499–505.
16. **Gorse, G. J., T. Z. O'Connor, S. L. Hall, J. N. Vitale, and K. L. Nichol.** 2009. Human coronavirus and acute respiratory illness in older adults with chronic obstructive pulmonary disease. J. Infect. Dis. **199:**847–857.
17. **Gorse, G. J., T. Z. O'Connor, F. K. Newman, M. D. Mandava, P. M. Mendelman, J. Wittes, and P. N. Peduzzi.** 2004. Immunity to influenza in older adults with chronic obstructive pulmonary disease. J. Infect. Dis. **190:**11–19.
18. **Gorse, G. J., T. Z. O'Connor, S. L. Young, P. M. Mendelman, S. F. Bradley, K. L. Nichol, H. J. Strickland, Jr., D. M. Paulson, K. L. Rice, R. A. Foster, A. M. Fulambarker, J. W. Shiqeoka, W. G. Kuschner, R. P. Goodman, K. M. Neuzil, J. Wittes, K. D. Boardman, and P. N. Peduzzi.** 2003. Efficacy trial of live, cold-adapted and inactivated influenza virus vaccines in older adults with chronic obstructive pulmonary disease: a VA cooperative study. Vaccine **21:**2133–2144.
19. **Gorse, G. J., E. E. Otto, D. C. Powers, G. W. Chambers, C. S. Eickhoff, and F. K. Newman.** 1996. Induction of mucosal antibodies by live attenuated and inactivated influenza virus vaccines in the chronically ill elderly. J. Infect. Dis. **173:**285–290.
20. **Graat, J. M., E. G. Schouten, M.-L. A. Heijnen, F. J. Kok, E. G. Pallast, S. C. de Greeff, and J. W. Dorigo-Zetsma.** 2003. A prospective, community-based study on virologic assessment among elderly people with and without symptoms of acute respiratory infection. J. Clin. Epidemiol. **56:**1218–1223.
21. **Greenberg, S. B., M. Allen, J. Wilson, and R. L. Atmar.** 2000. Respiratory viral infections in adults with and without chronic obstructive pulmonary disease. Am. J. Respir. Crit. Care Med. **162:**167–173.
22. **Gump, D. W., C. A. Phillips, B. R. Forsyth, K. McIntosh, K. R. Lamborn, and W. H. Stouch.** 1976. Role of infection in chronic bronchitis. Am. Rev. Respir. Dis. **113:**465–474.
23. **Hruskova, J., F. Heinz, E. Svandova, and S. Pennigerova.** 1990. Antibodies to human coronaviruses 229E and OC43 in the population of C.R. Acta Virol. **34:**346–352.
24. **Imai, Y., K. Kuba, S. Rao, Y. Huan, F. Guo, B. Guan, P. Yang, R. Sarao, T. Wada, H. Leong-Poi, M. A. Crackower, A. Fukamizu, C.-C. Hui, L. Hein, S. Uhlig, A. S. Slutsky, C. Jiang, and J. M. Penninger.** 2005. Angiotensin-converting enzyme 2 protects from severe acute lung failure. Nature **436:** 112–116.
25. **Kuypers, J., E. T. Martin, J. Heugel, N. Wright, R. Morrow, and J. A. Englund.** 2007. Clinical disease in children associated with newly described coronavirus subtypes. Pediatrics **199:**e70–e76.
26. **Lau, S. K. P., P. C. Y. Woo, C. C. Y. Yip, H. Tse, H. W. Tsoi, V. C. Cheng, P. Lee, B. S. Tang, C. H. Cheung, R. A. Lee, L. Y. So, Y. L. Lau, K. H. Chan, and K. Y. Yuen.** 2006. Coronavirus HKU1 and other coronavirus infections in Hong Kong. J. Clin. Microbiol. **44:**2063–2071.
27. **Monto, A. S., and S. K. Lim.** 1974. The Techumsch study of respiratory illness. VI. Frequency of and relationship between outbreaks of coronavirus infection. J. Infect. Dis. **129:**271–276.
28. **Mourez, T., A. Vabret, Y. Han, J. Dina, L. Legrand, S. Corbet, and F. Freymuth.** 2007. Baculovirus expression of HCoV-OC43 nucleocapsid protein and development of a Western blot assay for detection of human antibodies against HCoV-OC43. J. Virol. Methods **139:**175–180.
29. **Peiris, J. S. M., K. Y. Yuen, A. D. M. E. Osterhaus, and K. Stöhr.** 2003. The severe acute respiratory syndrome. N. Engl. J. Med. **349:**2431–2441.
30. **Perlman, S., and J. Netland.** 2009. Coronaviruses post-SARS: update on replication and pathogenesis. Nat. Rev. Microbiol. **7:**439–450.
31. **Principi, N., S. Bosis, and S. Esposito.** 2010. Effects of coronavirus infections in children. Emerg. Infect. Dis. **16:**183–188.
32. **Pyrc, K., B. Berkhout, and L. van der Hoek.** 2007. The novel human coronaviruses NL63 and HKU1. J. Virol. **81:**3051–3057.
33. **Pyrc, K., R. Dijkman, L. Deng, M. F. Jebbink, H. A. Ross, B. Berkhout, and L. van der Hoek.** 2006. Mosaic structure of human coronavirus NL63, one thousand years of evolution. J. Mol. Biol. **364:**964–973.
34. **Redfield, D. C., D. D. Richman, M. N. Oxman, and L. H. Kronenberg.** 1981. Psoralen inactivation of influenza and herpes simplex viruses and of virus-infected cells. Infect. Immun. **32:**1216–1226.
35. **Rihkanen, H., E. Rönkkö, T. Nieminen, K.-L. Komsi, R. Räty, H. Saxen, T. Ziegler, M. Roivainen, M. Söderlund-Venermo, L. Anne, T. Hovi, and A. Pitkäranta.** 2008. Respiratory viruses in laryngeal croup of young children. J. Pediatr. **152:**661–665.
36. **Schmidt, O. W., I. D. Allan, M. K. Cooney, H. M. Foy, and J. P. Fox.** 1986. Rises in titers of antibody to human coronaviruses OC43 and 229E in Seattle families during 1975-1979. Am. J. Epidemiol. **123:**862–868.
37. **Severance, E. G., I. Bossis, F. B. Dickerson, C. R. Stallings, A. E. Origoni, and A. Sullens.** 2008. Development of a nucleocapsid-based human coronavirus immunoassay and estimates of individuals exposed to coronavirus in a U.S. metropolitan population. Clin. Vaccine Immunol. **15:**1805–1810.
38. **Shao, X., X. Guo, F. Esper, C. Weibel, and J. S. Kahn.** 2007. Seroepidemiology of group I human coronaviruses in children. J. Clin. Virol. **40:**207–213.
39. **Sloots, T. P., P. McErlean, D. J. Speicher, K. E. Arden, M. D. Nissen, and I. M. Mackay.** 2006. Evidence of human coronavirus HKU1 and human bocavirus in Australian children. J. Clin. Virol. **35:**99–102.
40. **Vabret, A., T. Mourez, J. Dina, L. van der Hoek, S. Gouarin, J. Petitjean, J. Brouard, and F. Freymuth.** 2005. Human coronavirus NL63, France. Emerg. Infect. Dis. **11:**1225–1229.
41. **Vabret, A., T. Mourez, S. Gouarin, J. Petitjean, and F. Freymuth.** 2003. An outbreak of coronavirus OC43 respiratory infection in Normandy, France. Clin. Infect. Dis. **36:**985–989.
42. **van der Hoek, L., K. Pyrc, M. F. Jebbink, W. Vermeulen-Oost, R. J. Berkhout, K. C. Wolthers, P. M. Wertheim-van Dillen, J. Kaandorp, J. Spaargaren, and B. Berkhout.** 2004. Identification of a new human coronavirus. Nat. Med. **10:**368–373.
43. **van der Hoek, L., K. Sure, G. Ihorst, A. Stang, K. Pyrc, M. F. Jebbink, G. Petersen, J. Forster, B. Berkhout, and K. Überla.** 2005. Croup is associated with the novel coronavirus NL63. PLoS Med. **2:**e240.
44. **Van Elden, L. J. R., A. M. van Loon, F. van Alphen, K. A. Hendriksen, A. I. Moepelman, M. G. van Kraaij, J. J. Oosterheert, P. Schipper, R. Schuurman, and M. Nijhuis.** 2004. Frequent detection of human coronaviruses in clinical specimens from patients with respiratory tract infection by use of a novel real-time reverse-transcriptase polymerase chain reaction. J. Infect. Dis. **189:**652–657.
45. **Woo, P. C. Y., S. K. P. Lau, C.-M. Chu, K.-H. Chan, H.-W. Tsoi, Y. Huang, B. H. Wong, R. W. Poon, J. J. Cal, W. K. Luk, L. L. Poon, S. S. Wong, Y. Guan, J. S. Peiris, and K. Y. Yuen.** 2005. Characterization and complete genome sequence of a novel coronavirus, coronavirus HKU1, from patients with pneumonia. J. Virol. **79:**884–895.
46. **Woo, P. C. Y., S. K. P. Lau, H.-W. Tsoi, Y. Huang, R. W. S. Poon, C.-M. Chu, R. A. Lee, W. K. Luk, G. K. Wong, B. H. Wong, V. C. Cheng, B. S. Tang, A. K. Wu, R. W. Yung, H. Chen, Y. Guan, K. H. Chan, and K. Y. Yuen.** 2005. Clinical and molecular epidemiological features of coronavirus HKU1-associated community-acquired pneumonia. J. Infect. Dis. **192:**1898–1907.