Sindbis virus (SINV), a mosquito-borne virus that causes rash and arthritis, has been causing outbreaks in humans every seventh year in northern Europe. To gain a better understanding of SINV epidemiology in Finland, we searched for SINV antibodies in 621 resident grouse, whose population declines have coincided with human SINV outbreaks, and in 836 migratory birds. We used hemagglutination-inhibition and neutralization tests for the bird samples and enzyme immunoassays and hemagglutination-inhibition tests for the human samples. SINV antibodies were first found in 3 birds (red-backed shrike, robin, song thrush) during their spring migration to northern Europe. Of the grouse, 27.4% were seropositive in 2003 (1 year after a human outbreak), but only 1.4% were seropositive in 2004. Among 2,529 persons, the age-standardized seroprevalence (1999–2003) was 5.2%; seroprevalence and incidence (1995–2003) were highest in North Karelia (eastern Finland). Grouse may contribute to the epidemiology of SINV in humans.

Sindbis virus (SINV) was first recognized and isolated in 1952 from a pool of Culex pipiens and Cx. univittatus mosquitoes collected from a village in the Nile River delta in Egypt, after which the virus was named (1). SINV, a member of the western equine encephalomyelitis complex of the genus Alphavirus in the family Togaviridae, is an enveloped virus with a genome of single-stranded, positive-polarity, 11.7-kb RNA (2). SINV is present throughout the Old World but has never been found in the New World (the Americas). SINV seropositivity in humans has been reported in various areas, and antibodies to SINV have also been found from various bird (3–5) and mammal (6,7) species. The virus has been isolated from several mosquito species, frogs (8), reed warblers (9), bats (10), ticks (11), and humans (12–14).

Despite the wide distribution of SINV, symptomatic infections in humans have been reported in only a few geographically restricted areas, such as northern Europe, and occasionally in South Africa (12), Australia (15–18), and China (13). In the early 1980s in Finland, serologic evidence associated SINV with rash and arthritis, known as Pogosta disease (19). In 2002, SINV was confirmed as the causative agent of Pogosta disease by isolating the virus from acutely ill patients (14). The typical clinical picture of acute Pogosta disease consists of arthritis, itching rash, fatigue, mild fever, headache, and muscle pain (20). Since 1974 in Finland, the disease has occurred as epidemics of hundreds or even thousands of patients every seventh year (1974, 1981, 1988, 1995, 2002). Similar disease is also found in Sweden (Ockelbo disease) and Russian Karelia (Karelian fever).

Most clinical cases in Finland are reported during August and September; the ornithophilic late summer mosquito species, Culex and Culiseta, are presumed to be the primary vectors (21). Grouse (Tetraonidae) (4) and passerines (especially thrushes, Turdidae) (5,22) have been suggested as amplifying hosts for SINV in northern Europe. Grouse are of special interest because they have previously had a 6–7 year population cycle with population declines coinciding with SINV outbreaks (4,23,24). Migratory birds may also play a role in distributing SINV over long distances, as they do with West Nile and avian influenza viruses. Supporting information is provided by the fact that SINV is disseminated over vast geographic areas of Australia with...
isolates from widely separated locations sharing identical nucleotide sequences (25). Studies on antigenic relatedness
of alphaviruses have also suggested that progenitor alphaviruses are spread over long distances by birds (26). Fur-
thermore, phylogenetic studies have indicated that South African and northern European SINV strains are closely
related (14,27). Therefore, the hypothesis is that migratory
birds have carried the virus to northern Europe.

A previous human epidemiologic study on SINV from
Finland (4) reported an annual incidence of 2.7/100,000 dur-
ing 1989–1996 and a seroprevalence of 0.6% in women of
reproductive age during 1992. In addition, SINV antibodies
were found in a small number of game birds and mammals in
Ilomantsi, eastern Finland, during 1981–1983 (4). We stud-
iied the human epidemiology of SINV during an additional
7-year period in Finland and the seroprevalence of SINV in
resident grouse. Furthermore, we looked for SINV antibod-
ies in migratory birds arriving in northern Europe. Our aim
was to elucidate factors contributing to the epidemiologic
pattern of SINV infections in humans in Finland.

Methods

National Surveillance for SINV and Testing of Human
Serum Samples

We used data reported from January 1995 to Decem-
ber 2003 in our analysis of incidence of SINV in the Fin-
ish population. Since 1995, all Finnish clinical microbiol-
ogy laboratories have reported laboratory-confirmed (by
antibody detection) diagnoses of SINV infection to the Na-
tional Infectious Disease Registry, maintained by the Na-
tional Public Health Institute in Helsinki. Most laboratory
reporting is done electronically and includes date of speci-
men collection and patient’s date of birth, sex, and place
of treatment. Multiple reports for the same person received
within a 12-month period are combined as a single case.

For our analysis of the seroprevalence of SINV in the
Finnish population, we used all samples from October 6,
1999, to May 8, 2003, that were tested for SINV antibodies
at Helsinki University Central Hospital Laboratory. This
laboratory performs >70% of the SINV antibody testing in
Finland; other testing is performed by the Department of
Virology at the University of Turku. We included only the
most recent sample from patients with multiple samples;
we excluded samples from those who had acute SINV in-
fecion (immunoglobulin [Ig] M positive).

Testing of Migratory Birds

In 2004, blood samples were collected from migratory
birds in 2 bird observatories during their spring migration:
on Jurmo Island (59°50′N, 21°36′E) on May 18 and 19 and
in Tauvo (64°49′N, 24°37′E) May 24–27. In 2005, blood
samples were also collected in 2 different bird observatories
during the spring migration: on Lågskär Island (59°50′N,
19°55′E) May 22–25 and in Tauvo May 29–31. In addi-
tion, migratory bird samples were collected in Kokkola
archipelago (63°52′N, 23°4′E) on July 30, 2005 (Figure 1,
panel A). Birds were captured with mist nets and identified
by certified bird ringers. Blood samples were obtained by
absorbing blood from the veins of wings or feet into filter
paper slips and then dried. When possible, samples from
native birds were also collected into small glass capillary
tubes. Samples from migratory birds were collected with
the permission of the Animal Experiment Committee of
the University of Helsinki (permission no. HY75-04). We
used the English and scientific names of birds according to
Cramp et al. (28).

Serologic Testing

The human serum samples were examined for SINV
IgM and IgG antibodies by enzyme immunoassays (EIA)
and for SINV total antibodies by hemagglutination-in-
hibition (HI) testing. The protocols for EIA (29) and HI
(29,30), as well as the diagnostic criteria for acute infec-
tion and previous immunity (29), have been described. In
the incidence analysis, ≈25% of the seropositive diagnoses
were made by using EIA at the University of Turku, where
HI testing was not used.

The bird samples were screened for antibodies by
HI testing. Approximately 1 cm² of each blood-saturated
dry filter paper slip was cut into small pieces, and 1 mL
of Dulbecco phosphate-buffered saline plus 0.2% bovine
serum albumin was added to elute the blood. The resulting
dilution corresponded to an ≈1:10 serum dilution (19), as
verified by parallel titrations with blood (on filter paper)
and serum samples from a seropositive person, which were
used as controls. A liquid dilution (250 μL) was used for
HI analysis.

HI testing was performed with 2-fold dilutions (1:20–
1:640). Only titers ≥40 were considered positive. Perfor-
mance of the HI technique on bird samples was confirmed
by comparison with a set of HI-positive and HI-negative
human samples and with neutralization tests (NTs) in which
endpoint neutralizing antibody titers inhibiting cytopathic
effect on Vero E6 cells were determined ≈65 h after infec-
tion. All samples in the subset with an HI titer >40 (n = 7)
showed NT titers >20, and all samples in the subset with an
HI titer <20 (n = 8) showed NT titers <20. In addition, all
samples with borderline HI results were determined by NT
to be negative.
Results

Human Population

A total of 2,529 human specimens were included in our analysis. When the data were standardized according to the age distribution of the Finnish population, the estimated seroprevalence was 5.2% (Figure 2). Geographically, the seroprevalence was high in eastern Finland, especially in North Karelia and Kainuu, but also in central Ostrobothnia in western Finland (Figure 1, panel B). Seroprevalence was significantly higher for men (6.0%; mean age of all men studied 41.8 years) than for women (4.1%; mean age of all women studied 44.1 years) ($\chi^2 = 4.721, p<0.030$). Seroprevalence increased with age, reaching 15.4% among persons 60–69 years of age (Figure 2).

The incidence of SINV during epidemic years was 25.6/100,000/year in 1995 and 11.5/100,000/year in 2002 (Figure 1, panel B); the average annualized incidence in nonepidemic years (1996–2001 and 2003) was 2.4/100,000. The rates for women and men were 8.7 and 6.6/100,000, respectively. The average annualized incidence was highest (13.5/100,000) among persons 50–59 years of age (Figure 2). Rates were higher for persons in the eastern parts than in the central part of the country and were highest in North Karelia (25.7/100,000; Figure 1, panel C); incidence peaked in North Karelia and in southern Ostrobothnia during the 1995 and 2002 outbreaks (Figure 3). However, a year after the outbreak in 2003, the rates were twice as high in southern Ostrobothnia than in North Karelia (Figure 3).

Resident Grouse

A total of 340 blood samples were collected from resident grouse in 2003, and 281 samples were collected in 2004 (Table 1; Figure 1, panel D). In 2003, a year after a human outbreak, the total prevalence of SINV HI antibodies in the grouse was 27.4%; in 2004, it declined significantly to 1.4% ($\chi^2 = 76.8, p<0.001$). In 2003, the prevalence was high in North Karelia (44%), western Finland (south-
ern Ostrobothnia, Vaasa, and central Ostrobothnia) (44%), and Central Finland (41%), but pronounced also in Lapland in northern Finland (18%) (Figure 1, panel D). Also in 2003, 27.2% of the male grouse and 28.6% of the female grouse were seropositive; in 2004, 2.2% of the males and 1.3% of the females were seropositive (sex was unknown for 132/621 of the grouse). In 2003, 32.0% of the juveniles (born the same year) and 23.3% of the adults were seropositive; in 2004, none of the juveniles and 2.9% of the adults were seropositive (age was unknown for 96/621).

The distribution of antibody titers in the positive samples was as follows: 40–120 (32.0%), 160–480 (42.3%), and 640–>1,280 (25.8%).

**Migratory Birds**

A total of 836 blood samples were collected from migratory birds, of which 806 were collected during spring migration in May 2004 and May 2005. SINV HI antibodies were detected in 3 birds during spring migration: a robin (*Erithacus rubecula*) and a song thrush (*Turdus philomelos*) from Tauvo in 2004, and a red-backed shrike (*Lanius colurio*) from Lågskär in 2005 (Figure 1, panel A; Table 2). HI antibody titers were 240, 120, and 40, respectively. The song thrush was born the previous year; the age of the other 2 positive birds was unknown. SINV RNA could not be detected with reverse transcription–PCR (20) from the seropositive filter paper slip solutions. Virus isolation (14) from the available whole blood samples (kept at –70°C) from the seropositive robin and song thrush was not successful.

**Discussion**

Our findings show that SINV-seropositive migratory birds arrive in northern Europe during spring migration. Furthermore, after the 2002 outbreak in humans, SINV seroprevalence in grouse decreased markedly between the next 2 consecutive hunting seasons (2003 and 2004). These findings suggest that grouse may be involved in the epidemiology of SINV in humans.

The HI and EIA tests used in this study cross-react only poorly between alphaviruses in different antigenic complexes but may cross-react with other alphaviruses within the same antigenic complex. However, no viruses in the western equine encephalomyelitis complex other than SINV are known to circulate in northern Europe. Seroprevalence of SINV in the human population was analyzed for persons with suspected Pogosta disease; although this sample is not random and was recorded by the place of treatment (not residence), it does provide good representation of different geographic areas.

Although the incidence of SINV infection was higher in women than in men, the seroprevalence was higher in men. This unexpected finding might be explained by the possibility that infected men are more frequently asymptomatic than women, but more investigations are needed. The high seroprevalence but low incidence in Kainuu could be the result of considerable underdiagnosis.

Before 1965, no Finnish persons were found to be SINV seropositive (31); however, from 1981 to 1995, seroprevalence of SINV in the Finnish population rose considerably. In 1992, seroprevalence in pregnant women was 0.6% (4); in our study, seroprevalence in women 20–39 years of age was 2.3%, which further suggests a continuous increase in the seroprevalence of SINV in Finland. These data suggest that SINV may have been newly introduced to northern Europe during the 1960s to 1970s. As with West Nile virus, a candidate vehicle for the distribution of SINV is infected migratory birds.

Similar to the incidence we found, the incidence of SINV during 1980–1996 was highest in the provinces of North Karelia and Central Finland (4). In 2003, however, the incidence was highest in southern Ostrobothnia, possibly reflecting the high immunity to SINV in North Karelia after the 2002 outbreak.

In terms of age, 1 study found SINV seroprevalence in 1,850 hospital patients in Finland to be 19% in those...
patients <10 years of age (32). Our results are in contradiction to this because only 1.4% of persons <10 years of age were seropositive, and seroprevalence increased gradually by age, which we consider a logical finding. In those 60–69 years of age, almost one sixth of the population had immunity to SINV. Considering the high infection rate and that the infection may cause prolonged joint symptoms (20, 33–35), even objectively observed by a physician (36), the disease is a potential public health concern.

In 1982 in Sweden, most of the 65 serologically diagnosed cases occurred in August. Incidence was highest for men 30–39 years of age and women 50–59 years of age, and prevalence was highest in central Sweden during the same period, which suggests that these species may be important enzootic vectors in a bird–mosquito cycle. In 1983, Francy et al. isolated 14 SINV strains from ≈60,000 female mosquitoes in Sweden. Most were isolated from Cx. pipiens, Cx. torrentium, and Culiseta morsitans, and seropositive birds were detected during a similar period, which suggests that these species may be important enzootic vectors in a bird–mosquito cycle. In 1983, any seropositive titers were not found in the few hundred migratory birds that arrived on the Swedish coast; in the same year, antibody prevalence in nesting birds (residents and migrants) was 3.4% in July and 10% in August (21). In the United Kingdom, SINV antibodies have also been demonstrated in resident and migrant birds and in poultry (3).
SINV-antibody prevalence in passerine birds sampled in Sweden between June and August during the 1990s (i.e., not during spring migration)—fieldfare (43.3%), redwing (37.0%), and song thrush (22.2%)—was markedly higher than the average (7.7%) of all species studied (5). The prevalence was significantly higher for birds sampled after the hatching year (13.9%) than for birds sampled during the hatching year (2.4%).

Of the seropositive migratory birds reported here, robin and song thrush mainly spend the winter in western Europe (some individuals migrate to northwestern Africa (28), and red-backed shrike spend the winter in eastern tropical and southern Africa (28). Altogether, 806 of the 836 samples were collected during spring migration in bird observatories, which is usually where the birds first land when they arrive in the country from the sea; the other 30 were collected during midsummer. However, virus infection during the previous year in northern Europe cannot be excluded. Detection of viable SINV in the migrating birds would be the ultimate proof for their involvement in distributing SINV, but that remains to be shown. Extended longitudinal studies are needed to determine whether resident reservoir species are able to sustain SINV cycles endemically in northern Europe or whether the virus must be repeatedly introduced there by migratory birds from the southern hemisphere. Although the similarity of mosquito isolates of SINV from Sweden and Russia in 1980s and from Finnish patients in 2002 (14) favors the endemic cycle, larger analyses of SINV strains from Africa and northern Europe (40) suggest a continuous importation of South African strains to northern Europe or vice versa.

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