

importance of surveillance at points of entry to mitigate the risk for ASFV introduction through illegal imports.

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Hepatitis E Virus Infection in European Brown Hares, Germany, 2007–2014

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Rabbit-associated hepatitis E viruses (HEVs) cause zoonotic infections. We investigated 2,389 hares in Germany during 2007–2014. Complete genome characterization of a hare-associated HEV strain revealed close genomic relatedness to rabbit-associated HEV strains. Although hare-specific HEV seroprevalence was low, at 2.6%, hares represent a potential source of sporadic HEV infections.

Hepatitis E virus (HEV; family Hepeviridae, genus *Orthohepevirus*) is a major cause of acute hepatitis in humans worldwide. Large outbreaks have included waterborne HEV in the tropics and zoonotic infections in temperate climates (1). In 2017, researchers identified human infection with HEV strains associated with rabbits (raHEV) in France (2,3).

In Germany, rabbits (family Leporidae, genus *Oryctolagus*) are common in the wild but are also popular pets, potentially explaining human exposure to raHEV. Hares (family Leporidae, genus *Lepus*), although genetically related, are physically larger and are primarily hunted as food in large parts of Europe (>5 million hares annually) (4). HEV associated with hares (haHEV) had been previously unknown (5). For this study, we tested for HEV in 2,389 European brown hares (*L. europaeus*) hunted in Germany during 2007–2014, across an area of ≈30,000 km² (Appendix Figure 1, <http://wwwnc.cdc.gov/EID/article/25/6/18-1618-App1.pdf>). One animal (0.04% of all samples; 95% CI 0.03%–0.05%) tested positive in a broadly reactive reverse transcription PCR assay; 25 (2.6%; 95% CI 1.6%–3.5%) animals were identified as seropositive.

RNA concentration was 5.4×10^4 IU/mL in the serum of the animal that tested positive, comparable to viral loads observed in rabbits and in human blood donors (3,6). After we determined its complete viral genome (GenBank accession

no. MK050463), the haHEV isolate showed the typical genome organization of *Orthohepevirus A*, including 3 predicted open reading frames (ORF). We found a 93-nt insertion in the X-domain of ORF1 that is thought to be typical of raHEV strains and absent in other HEV strains (2,3). This finding may reflect a common origin of raHEV and haHEV strains or a host-associated virus adaptation. We found no evidence for recombination of haHEV with other *Orthohepevirus* species or subtypes.

When averaged over the complete genome, the haHEV isolate we obtained shared 86% nucleotide identity with the most closely related raHEV strain (GenBank accession no. KY436898), from a rabbit sampled in Germany in 2016 (5). Average translated amino acid identity of the haHEV with raHEV strains was high at 88.5%–97.5% for ORF1, 90.2%–98.5% for ORF2, and 88.6%–95.1% for ORF3. In phylogenetic reconstructions, the haHEV clustered with raHEV strains, further suggesting a common origin for haHEV and raHEV, and suggesting an origin of haHEV in ancestors carried by rabbits and distinct from the greater HEV diversity existing in swine (7) (Figure; Appendix Figure 2). This interpretation is consistent with sporadic sharing of habitats between wild rabbits and hares in the study area.

To determine seroprevalence, we expressed the capsid protein of haHEV and used it for indirect immunofluorescence assays (Appendix). In total, serum samples from 944 hares, covering all sampling regions and years, were available in sufficient quality and quantity for serological testing (Appendix Table 2). HEV seroprevalence for hares was 2.6% (95% CI 1.6%–3.5%), similar to values in a previous serologic study of 669 European brown hares that used a capsid fragment from a human HEV genotype 1 strain as antigen and yielded a seroprevalence of 1.6%–4.3% (5). The sampling sites from that study were up to 400 km from those in our study, suggesting geographically widespread HEV infection of hares. That study also found wild rabbits to be seropositive at rates >35% (5). The lower HEV seroprevalence in hares than in rabbits might be explained by the fact that hares live solitarily and have low-density populations, ≈12–20 animals/100 ha in the sampling region; wild rabbits live in groups of ≈15 that are also proximal to other groups.

We found no statistically significant differences in seroprevalence for hares <1 versus >1 year of age (χ^2 0.08; $p = 0.78$), which is unlike the age-dependent increase of seropositivity observed in pigs and humans (8,9). Explanations may include a lack of statistical power in this study or differential pathogenesis of HEV in hares. Although the data

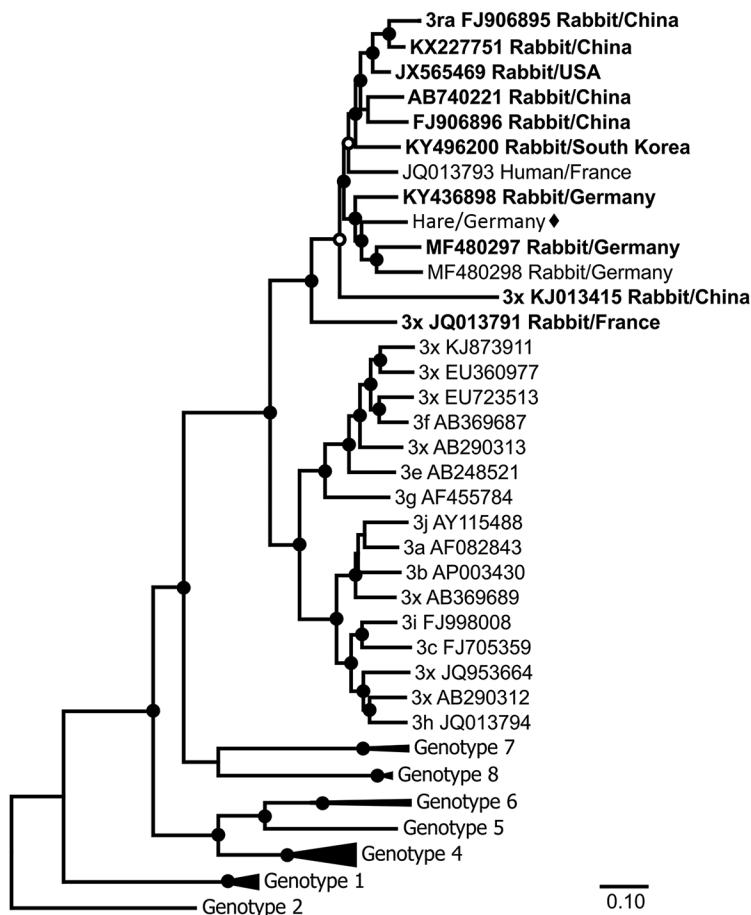


Figure. Maximum-likelihood phylogeny of the concatenated open reading frame 1 and 2 nucleotide sequences of hare hepatitis E virus (HEV) strain from Germany (black diamond), related strains from rabbits (bold) and humans, and reference *Orthohepevirus A* strains, as defined by Smith et al. (7). Taxon names of all reference sequences include genotype, subtype (x if not available), and GenBank accession number. Black circles at nodes indicate bootstrap supports of >90% and white circles >75% (1,000 replicates). The clades comprising sequences other than HEV genotype 3 were collapsed for graphical reasons. Scale bar indicates nucleotide substitutions per site.

on HEV pathogenesis in rabbits are in part controversial, occurrence of HEV in apparently healthy laboratory rabbits suggests that rabbits frequently survive HEV infection (10). Whether the apparently low seroprevalence in hares compared with rabbits is thus due to infrequent infection, differential antibody responses, or other host- or virus-associated factors remains to be determined.

We detected no statistically significant differences in seroprevalence rates, either between sexes (χ^2 0.01; $p = 0.92$) or across the 8 sampling years (Yates χ^2 0.6; $p = 0.96$) and the 5 individual sampling regions (Yates χ^2 1.945; $p = 0.96$). These findings suggested constant low levels of HEV transmission in hares irrespective of sex and geographic region.

The infection of hares with HEV strains that are closely related to raHEV strains suggests that hares may act as sporadic sources of zoonotic HEV infections. Although the low RNA detection rate and seroprevalence speak against a prominent role of hares in the epidemiology of zoonotic HEV, hunters and persons handling hare-derived products could represent risk groups. Awareness about hare-derived HEV infections may be particularly relevant for immunocompromised persons, in whom chronic HEV infections are most common.

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Sarcoptic Mange of Fox Origin in Multiple Farm Animals and Scabies in Humans, Switzerland, 2018

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Fox-derived *Sarcoptes scabiei* mites caused an outbreak of mange on a farm in Switzerland in 2018. Pruritic skin lesions suggestive of *S. scabiei* mite infestation developed in 4 humans who had direct contact with affected farm animals but not foxes. Sarcoptic mange is continuously spreading; such outbreaks affecting humans could start occurring more frequently.

Hepatitis E Virus Infection in European Brown Hares, Germany 2007–2014

Appendix

Sampling

A total of 2,389 serum specimens obtained from European brown hares (*Lepus europaeus*) were available for this study (Appendix Table 1). Samples were collected from dead hares during hunting days in 25 counties, summarized into 5 regions of Lower Saxony between 2007 and 2014 (Appendix Figure 1). Hare blood was sampled by heart punctation shortly after death. Serum samples were obtained after centrifugation of coagulated blood sample at $3,000 \times g$ for 15 minutes. All samples were stored at -20°C until further processing. Data on age of 880 hares was determined by the mean dry weight of the eye lenses (*1*). Here, we used 280 mg as the borderline value of mean eye lenses weight between juvenile (<1 year) and adult hares (>1 year) as described elsewhere (*1*). Data about hare and rabbit density and ecology were obtained from the annual hunting reports published from the Ministry of Food, Agriculture, and Consumer Protection, Lower Saxony (*1*) and from own observations.

Viral nucleic acid detection and complete genome sequencing

Viral RNA was extracted with the QiaCube HT (QIAGEN, Hilden, Germany) using 20 μl of serum from all 2,389 individual hares. Screening for hepatitis E virus (HEV) RNA was done using a highly sensitive and broadly reactive nested reverse transcription-PCR (RT-PCR) assay (oligonucleotides are given in Appendix Table 3) amplifying a 283 nt fragment of the *RNA-dependent RNA-polymerase* gene as previously described (*2*). The amplified RT-PCR screening fragment was Sanger sequenced (Seqlab Göttingen, Germany).

The HEV RNA concentration in the positive sample was determined by using a real-time RT-PCR assay (oligonucleotides are given in Appendix Table 3) designed for the detection and quantification of *Orthohepevirus A* (*3*). The World Health Organization International Standard for HEV (*4*) was used for calibration.

To obtain the full sequence of the hare HEV genome, heminested reverse transcription-PCR (RT-PCR) assays were developed (Appendix Table 3). These assays were designed to amplify ≈ 800 overlapping nucleotides of known *Orthohepevirus A* genotype 3 genomes. Genomic fragments that could not be amplified by these assays were connected by bridging RT-PCR using hare HEV-specific primers (Appendix Table 3). All PCR products were Sanger sequenced (Microsynth Seqlab, Göttingen, Germany).

For the phylogenetic analyses, the complete coding sequences of the concatenated ORF 1 and ORF 2 of hare-associated HEV were aligned with other lagomorph HEV strains available in GenBank as of 1st Sep 2018, and reference *Orthohepevirus A* strains, as previously defined (5). Maximum likelihood phylogenies were calculated using a GTR nucleotide substitution model, neighbor-joining phylogenies with a Jukes-Cantor nucleotide substitution model and 1000 bootstrap replicates in Geneious 11 (<https://www.geneious.com/>). Recombination analyses were made using RDP4 (6).

Antibody detection

Recombinant capsid Immunofluorescence Assay (IFA)

For expression of the viral capsid protein, the hare HEV capsid gene obtained from complete genome sequencing was codon-optimized for expression in primate cells (<http://eu.idtdna.com/CodonOpt>) and synthesized (Integrated DNA Technologies, Leuven, Belgium) including a C-terminal FLAG-tag. The synthesized gene was cloned into a pCG1 eukaryotic expression vector (kindly provided by Georg Herrler, University of Veterinary Medicine Hannover, Foundation, Hanover) and its sequence confirmed by re-sequencing. Vero B4 cells were transfected in suspension using 2.5 μg of plasmid DNA and the FuGENE HD protocol (Roche, Basel, Switzerland). Transfected cells were seeded into a 6-well plate. After 24 hours, cells were washed, trypsinized and transferred to multitest glass slides (Dunn Labortechnik, Asbach, Germany). After 6 hours, cells were fixated with ice cold acetone/methanol and stored dry at 4°C. As the C-terminal flag tag will be only expressed when the upstream viral gene is intact, we used a mouse anti-FLAG antibody (Sigma-Aldrich Chemie GmbH), diluted 1:100 and a Cy3-labeled goat anti-mouse antibody, diluted 1:200 (Jackson ImmunoResearch Laboratories, Ely, UK) to confirm expression of viral proteins.

For validation of our recombinant capsid IFA, we used five human sera shown to be positive for anti-Hepatitis E IgG by a human-specific Anti-HEV IgG ELISA (Axiom Diagnostics Worms, Germany) and the HEV recomLine Immunoblot (MIKROGEN, Neuried, Germany) as well as a serial dilution (50 IU/ml down to 0.5 IU/ml) of the WHO reference reagent for antibodies to hepatitis E virus (NIBSC code: 95/584) (7). Human serum samples and the reference reagent were applied at a dilution of 1:40 and detection involved a goat anti-human IgG coupled with Alexa 488 (Dianova, Hamburg, Germany) diluted 1:200. All five sera reactive in ELISA were also positive in the hare HEV capsid-based IFA. Five human sera testing negative in the IgG ELISA showed no signal in the hare HEV capsid-based IFA (Appendix Figure 3). The WHO reference reagent showed positive signal down to a concentration of 1 IU/ml in the IFA (Appendix Figure 4). To further validate the recombinant capsid IFA for hare-derived samples, we first tested the HEV RNA positive hare sample by using the recombinant IFA slides and by using different dilutions (1:40 to 1:4,000) of the hare serum, the secondary (AffiniPure Goat Anti-Rabbit IgG (H+L); Jackson ImmunoResearch Laboratories) and tertiary antibody Cy3 labeled-AffiniPure Donkey Anti-Goat IgG (H+L; Jackson ImmunoResearch Laboratories) in the range of 1:100 to 1:2,000. The secondary and tertiary antibodies were found to show best signals without background noise at a dilution of 1:1,500 and 1:200, respectively. The absence of any signal by using the tertiary antibody without preincubation of the secondary (Goat Anti-Rabbit IgG) excludes unspecific signal of the tertiary antibody (Donkey Anti-Goat IgG) with the cells. For hare HEV antibody screening, hare serum samples were applied at a dilution of 1:40 for 1 h at 37°C. As an example, the IFA of the HEV RNA positive and IFA reactive hare serum sample is shown in Appendix Figure 5. Untransfected cells served as internal negative controls.

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Appendix Table 1. Number and origin of hare serum samples used for HEV RT-PCR screening*

| Sample origin | | Year of sampling | | | | | | | | |
|---------------|------------------|------------------|------------|------------|------------|-----------|------------|-----------|-----------|--------------|
| Region | County | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
| CE | | 56 | 70 | 53 | 27 | | | 7 | | 213 |
| | Celle | | 21 | | | | | | | 21 |
| | Diepholz | | | 39 | 27 | | | | | 66 |
| | Hannover, Region | 56 | | 14 | | | | 7 | | 77 |
| | Nienburg | | 35 | | | | | | | 35 |
| | Wolfsburg | | 14 | | | | | | | 14 |
| CW | | 73 | 54 | 62 | | | | | | 189 |
| | Cloppenburg | | 13 | | | | | | | 13 |
| | Emsland | 38 | 13 | | | | | | | 51 |
| | Oldenburg | | | 54 | | | | | | 54 |
| | Osnabrück | 35 | | | | | | | | 35 |
| | Vechta | | 28 | 8 | | | | | | 36 |
| NE | | | 113 | 14 | | | | | | 127 |
| | Harburg | | 16 | 14 | | | | | | 30 |
| | Lüneburg | | 22 | | | | | | | 22 |
| | Rotenburg | | 30 | | | | | | | 30 |
| | Stade | | 14 | | | | | | | 14 |
| | Verden | | 31 | | | | | | | 31 |
| NW | | 3 | 111 | 99 | 92 | | | | | 305 |
| | Ammerland | | 51 | | | | | | | 51 |
| | Aurich | | 19 | | | | | | | 19 |
| | Osterholz | | 10 | | | | | | | 10 |
| | Wesermarsch | | | 4 | 51 | | | | | 55 |
| | Wittmund | 3 | 31 | 95 | 41 | | | | | 170 |
| SE | | 257 | 357 | 224 | 483 | 54 | 158 | 10 | 12 | 1,555 |
| | Goslar | 5 | | | | | | | | 5 |
| | Göttingen | 33 | | | | | | | | 33 |
| | Hildesheim | | 39 | | 33 | | | | | 72 |
| | Northeim | 40 | | | | | | | | 40 |
| | Peine | 179 | 318 | 224 | 450 | 54 | 158 | 10 | 12 | 1,405 |
| | Total | 389 | 705 | 452 | 602 | 54 | 158 | 17 | 12 | 2,389 |

*CE, Central-East; CW, Central-West; NE, North-East; NW, North-West, SE, South-East

Appendix Table 2. Number and origin of hare serum samples used for antibody testing (number of IFA positive samples)*

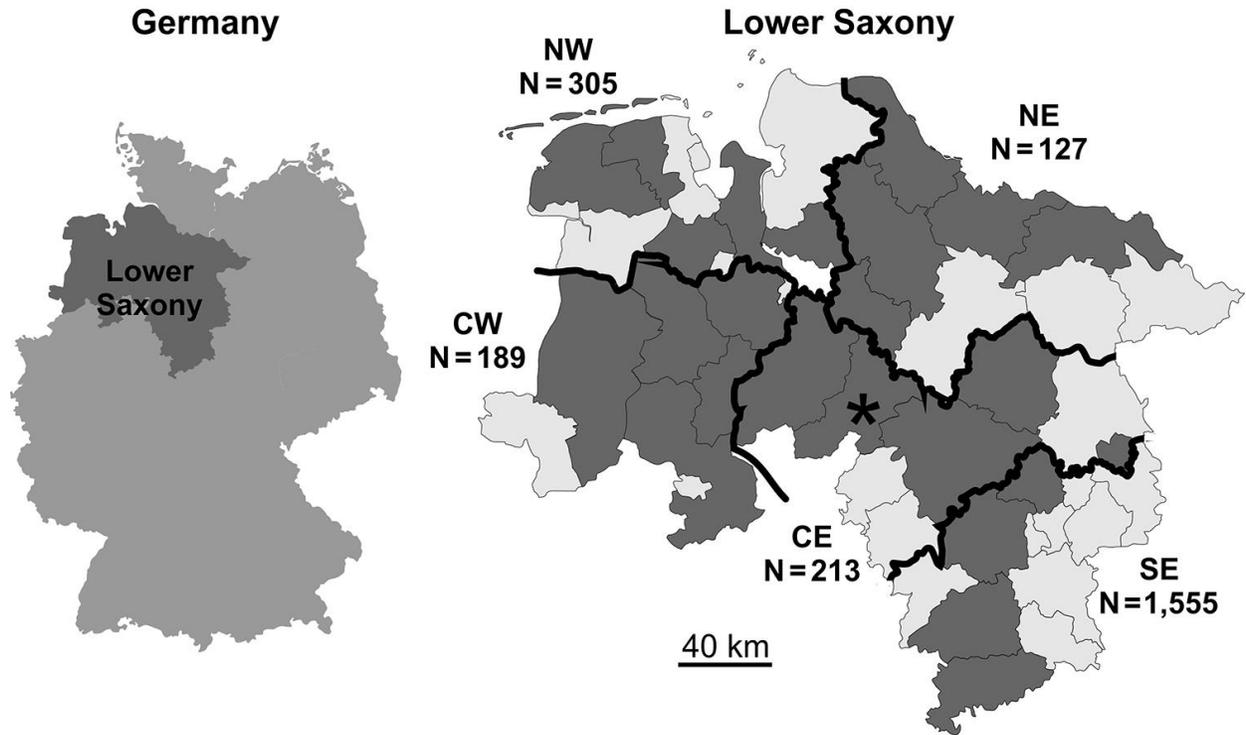
| Sample origin | | Year of sampling | | | | | | | | |
|---------------|---------------------|------------------|-----------------|----------------|----------------|---------------|---------------|----------|---------------|-----------------|
| Region | | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total (pos.) |
| CE | | 29 | 66 (5) | 44 (1) | 21 | | | 7 | | 167 (6) |
| CW | | 60 | 54 (2) | 38 (2) | | | | | | 152 (4) |
| NE | | | 113 (2) | 14 | | | | | | 127 (2) |
| NW | | 3 | 89 (1) | 34 | 60 (3) | | | | | 186 (4) |
| SE | | 90 (3) | 60 (1) | 30 | 60 (1) | 30 (2) | 30 (1) | | 12 (1) | 312 (9) |
| | Total (pos.) | 182 (3) | 382 (11) | 160 (3) | 141 (4) | 30 (2) | 30 (1) | 7 | 12 (1) | 944 (25) |

CE, Central-East; CW, Central-West; NE, North-East; NW, North-West, SE, South-East

Appendix Table 3. Oligonucleotides used for RT-PCR screening, complete genome sequencing, and virus quantification

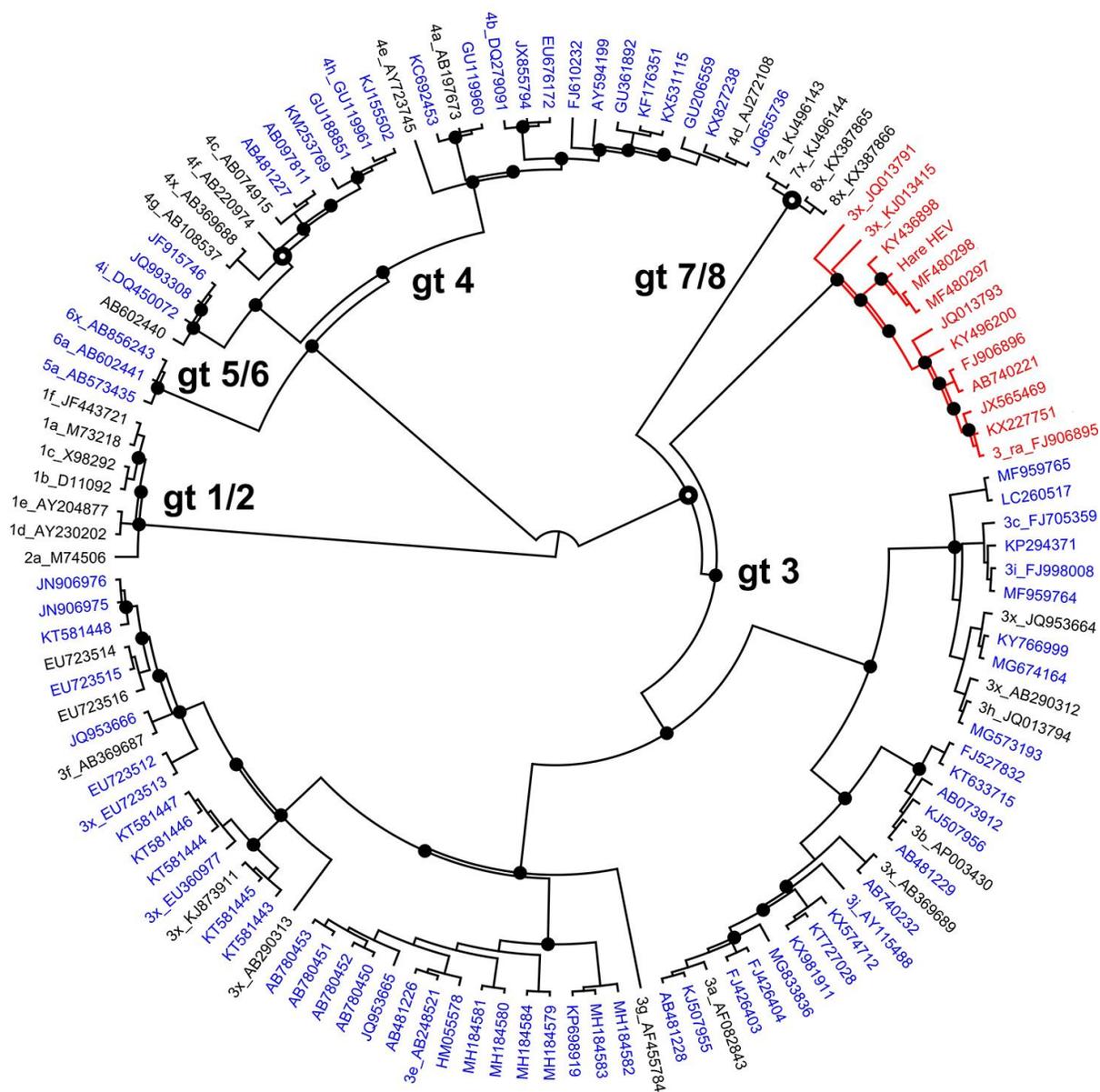
| Virus targeted | Oligonucleotide | Sequence (5' – 3') | Use | Reference |
|----------------------------|-----------------|--------------------------------|---|------------|
| Orthohpeviruses A–D | HEV-F4228 | ACYTTYTGTGTCYTTITTTGGTCCITGGTT | Heminested screening RT-PCR | (2) |
| | HEV-R4598 | GCCATGTTCCAGAYGGTGTTC | | |
| | HEV-R4565 | CCGGGTTTCRCCIGAGTGTTCCTTCCA | | |
| Orthohpevirus A | OrthoHEV_A-rtF | GGTGGTTTTCTGGGGTGAC | Quantitative real-time RT-PCR | (3) |
| | OrthoHEV_A-rtP | FAM-TGATTCTCAGCCCTTCGC-MGB | | |
| | OrthoHEV_A-rtR | AGGGGTTGGTTGGRTGRA | | |
| Orthohpevirus A genotype 3 | HEV-F4228 | ACYTTYTGTGTCYTTITTTGGTCCITGGTT | Heminested RT-PCRs for full-genome sequencing | This study |
| | HEVgt3–4611F | GGAAGAAGCAYTCYGGTGAGC | | |
| | HEVgt3–5305F | GTGGTTTCTGGGGTGACAGG | | |
| | HEVgt3–5325Fn | GTTGATTCTCAGCCCTTCGC | | |
| | HEVgt3–5349Rn | GGTTGGTTGGATGAATATAGGG | | |
| | HEVgt3–5448R | GCTGGGACTGGTCRCGCCA | | |
| | HEVgt3–5958F | GGNTGGCGCTCNGTNGAGAC | | |
| | HEVgt3–6000R | AGCATTACCAGRCCRGARGTAGC | | |
| | HEVgt3–6341F | GACAGAATTRATTTTCGTCGGC | | |
| | HEVgt3–6341Rn | GCCGACGAAATYAATTCTGTC | | |
| | HEVgt3–6378Fn | TACTCCC GCCCRGTGTCTC | | |
| | HEVgt3–6393R | GCTCGCCATTGGCYGAGAC | | |
| | HEVgt3–7145R | TCCCGRGTTRCCYACCTTCA | | |
| Hare/Rabbit HEV | Hare3Screen-F | CTAATTCGGTCGACCTGGATCC | Heminested RT-PCRs for full-genome sequencing | This study |
| | HaHEV3Screen-Fn | GGATCCTACAGGCTCCAAAGG | | |
| | HaHEV-R4565 | CCGGGTTTCRCCIGAGTGTTCCTTCCA | | |
| | HaHEV-R4598 | GCCATGTTCCAGAYGGTGTTC | | |
| | HaHEV-4979F | CAGTTACGCTTGGCTGTTTGC | | |
| | HaHEV-F 5212 | GCATCGCCCATGGGTTTAC | | |
| | HEVgt3P3-R | TGBAGCATRCCRATAAGGTTATG | | |
| | HEVgt33-Rnest | TARACHCGVGAMACAACATCMAC | | |
| | HaHEV-5255F | GCTGTTTCGTCTGTGTTTGC | | |
| | HaHEV-5142Fs | CTGTCAAGCCTGTGTTAGACC | | |
| | HaHEV-5050F | GTCCCGTGTTTATGGTGTGAGC | | |
| | HaHEV-6162F | CTTGAGATTGAGTTCCGCAACC | | |
| | HaHEV-6186F | ACTCCAGGGAACACCAACACAC | | |
| | HaHEV-6321R | TCTACCAACCCCGTTCATCC | | |
| | HaHEV-6347R | TAATGTCAGGGCTATGCCACG | | |
| | HaHEV-7231R | GGCACAACAAGAATTAATTAATAACTCC | | |
| | HaHEV-7246R | GCAATATAGAAGGGGGCACAAC | | |
| | HaHEV-3R-F | CTGTCTCTATCTCTGCAGTCCG | | |
| | HaHEV-3R-Fn | CTGTTCTAGCTGTCCCTTGAGG | | |
| | HaHEV-3R-Fs | CTAGCTGTCCCTTGAGGATACTACTG | | |

*Equally mixed base ratios in the sequences are represented as standard code letters: R is G/A, Y is C/T, S is G/C, W is A/T, M is A/C, K is G/T, H is A/C/T, B is C/G/T, N is A/T/C/G, and I is inosine. FAM, 6-carboxyfluorescein; MGB, minor groove binder.

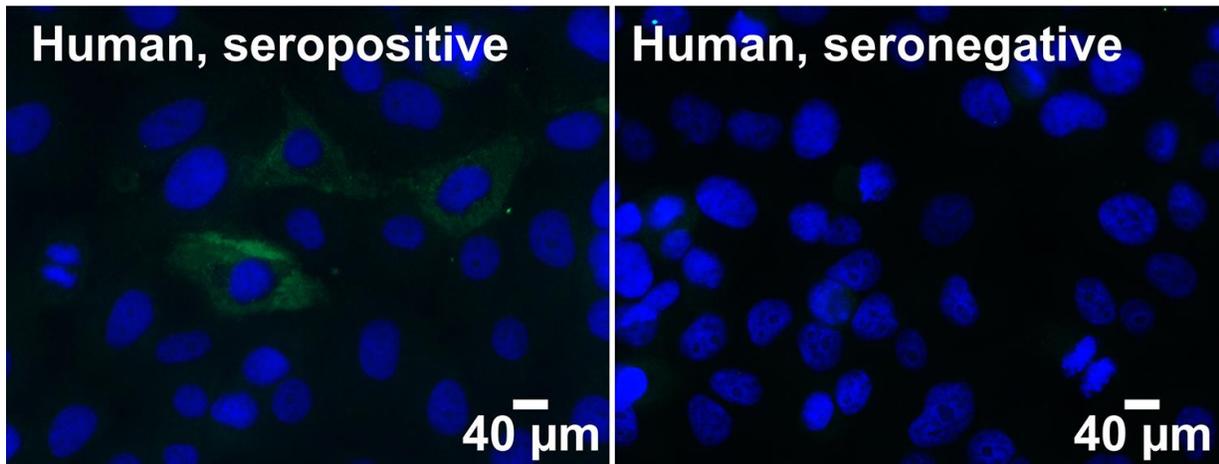


Appendix Figure 1. Number of hare samples available for molecular testing. The county where the HEV RNA positive sample was detected is marked with an asterisk. Map was created by using Quantum GIS (<http://qgis.osgeo.org>). CE, Central-East; CW, Central-West; NE, North-East; NW, North-West, SE, South-East.

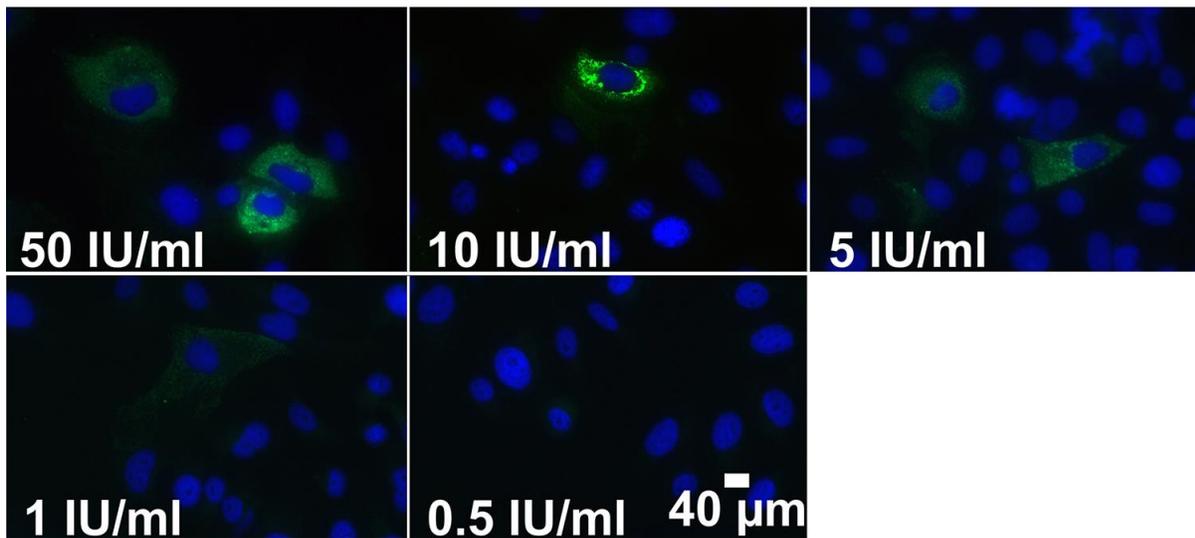
Orthohepevirus A



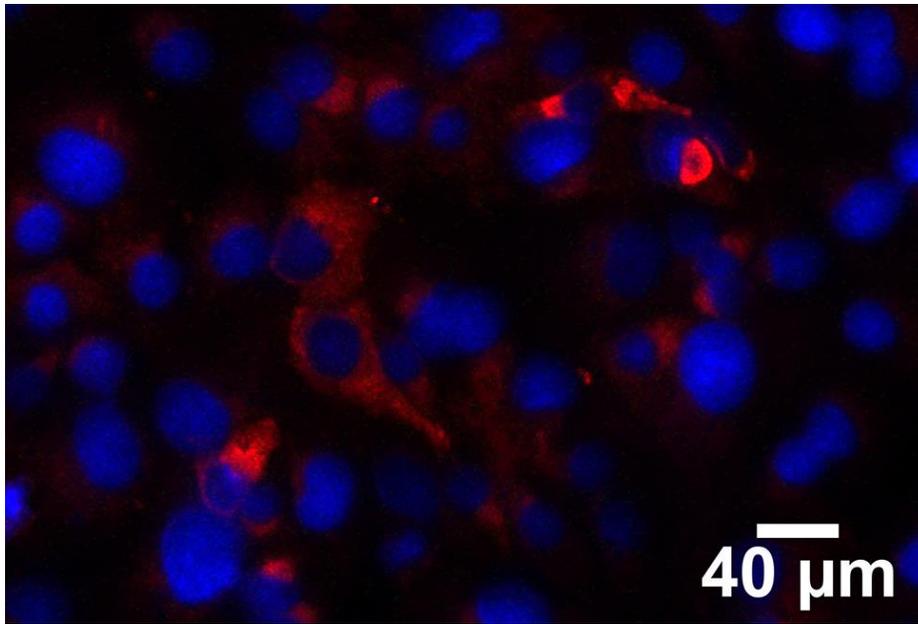
Appendix Figure 2. Neighbor-joining phylogeny of the concatenated ORF 1 and 2 nt sequences of the lagomorph-associated HEV strain, reference sequences for *Orthohepevirus A* strains/subtypes, as defined by Smith et al. (5), and all complete genome sequences from pigs and wild boars available in GenBank as of 1st January 2019. Taxon names of all reference sequences include genotype, subtype (“x” if not available), and GenBank accession number. Black circles at deeper nodes indicate bootstrap supports of >90% and white circles >75% (1000 replicates). All sequences obtained from swine are given blue. gt, genotype



Appendix Figure 3. Example of an anti-hepatitis E IgG positive and negative human serum sample (serum dilution, 1:40) in the recombinant hare HEV capsid-based indirect immunofluorescence assay. HEV antibodies are tagged with a green fluorophore. Nuclei are stained with DAPI (blue).



Appendix Figure 4. Serial dilution (50 IU/ml down to 0.5 IU/ml) of the WHO reference reagent for antibodies to hepatitis E virus (NIBSC code: 95/584) tested in the recombinant hare HEV capsid-based indirect immunofluorescence assay. HEV antibodies are tagged with a green fluorophore. Nuclei are stained with DAPI (blue).



Appendix Figure 5. Example of a HEV-reactive hare serum sample (serum dilution, 1:40) in the recombinant hare HEV capsid-based indirect immunofluorescence assay. HEV antibodies are tagged with a red fluorophore. Nuclei are stained with DAPI (blue).