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(54) **MURINE ASTROVIRUSES**

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(57) **ABSTRACT**

Novel murine astroviruses, and methods of detecting the viruses are disclosed. Also disclosed are uses of the viruses and infected animals as model systems for discovery and development of vaccines and therapies for diseases caused by or associated with astrovirus infection, including human astrovirus-based diseases.

(21) Appl. No.: **13/957,124**

FIG. 1

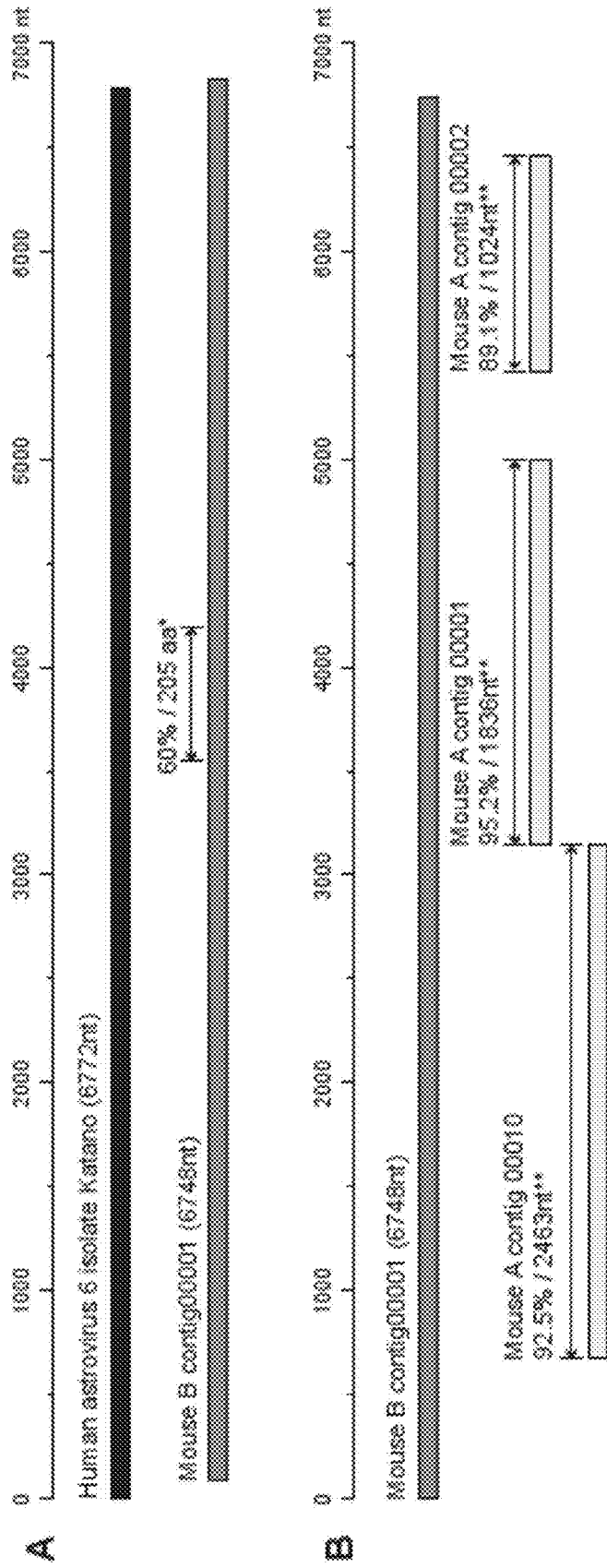


FIG. 2

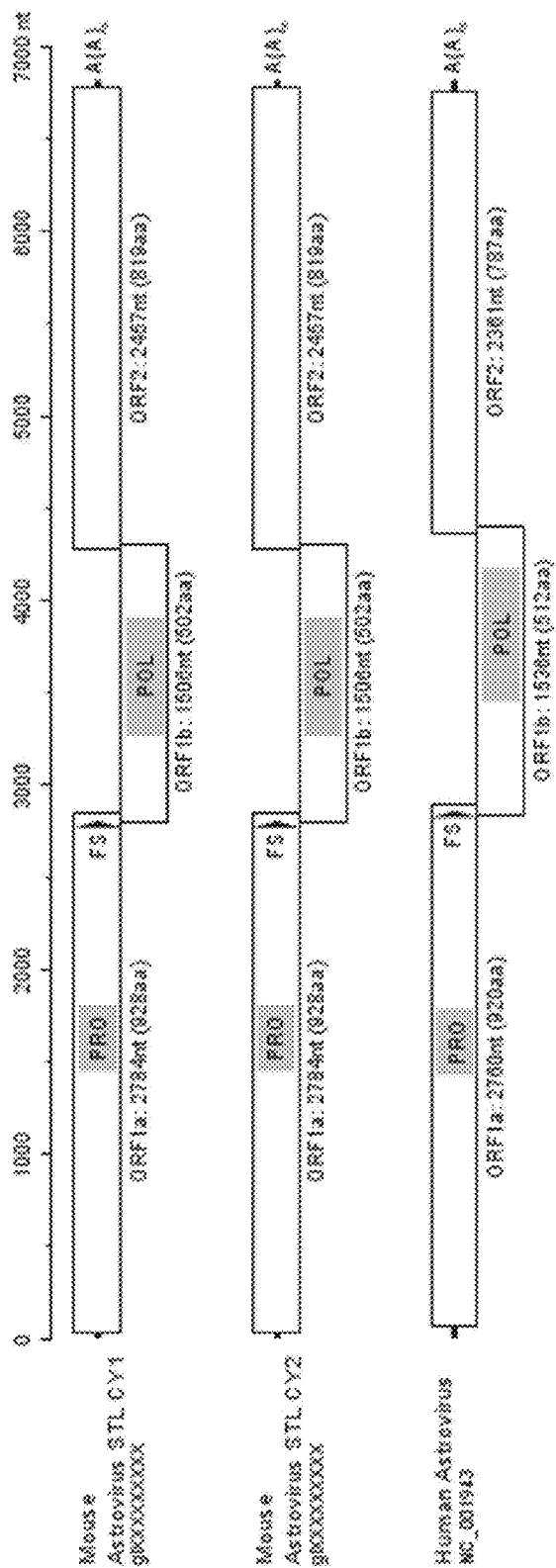


FIG. 3

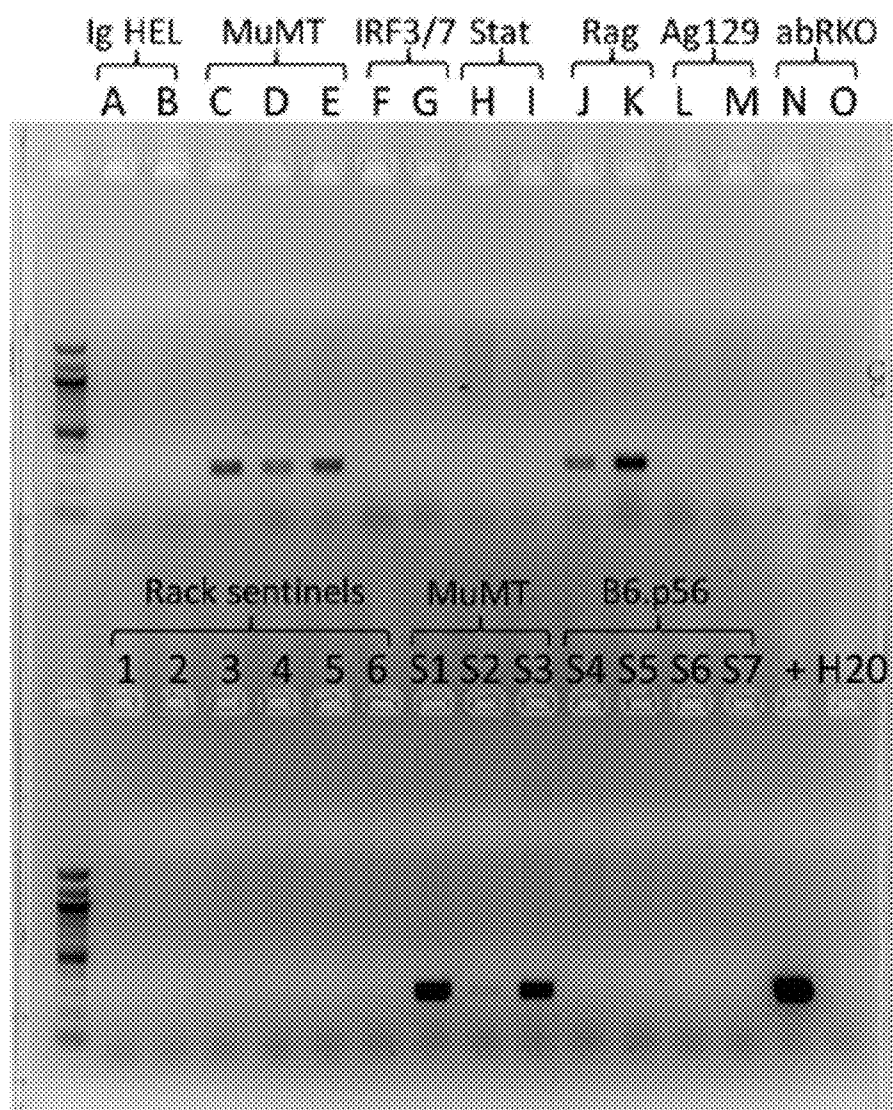


FIG. 4

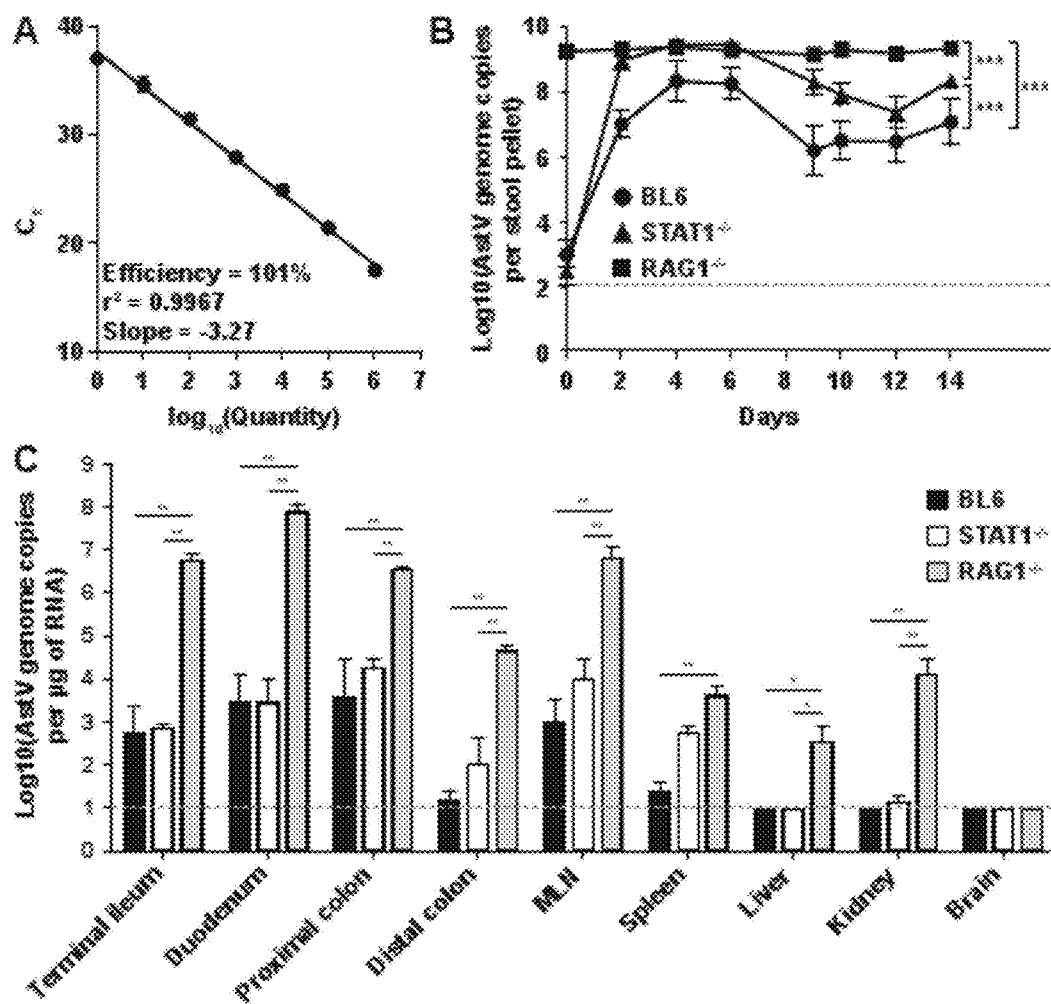


FIG. 5

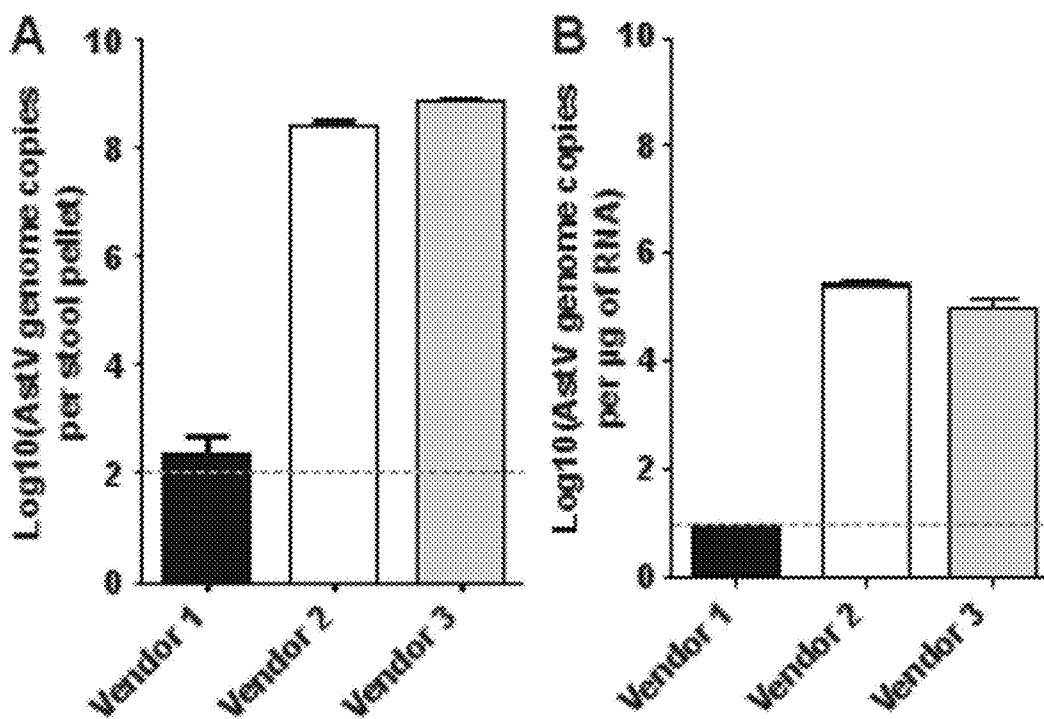


FIG. 6

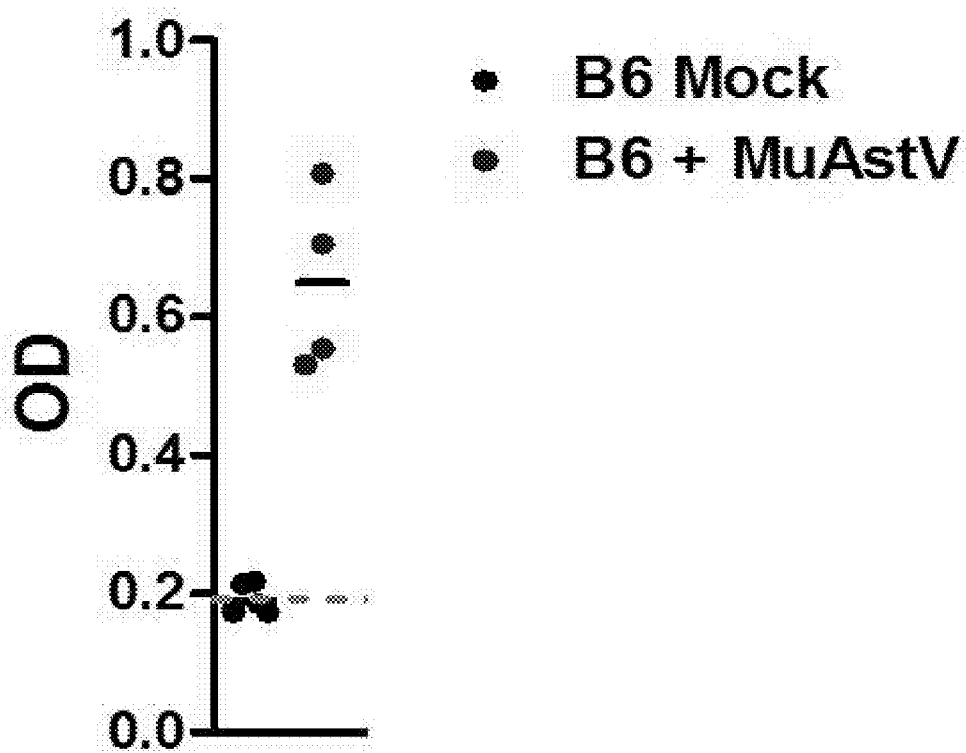


FIG. 7

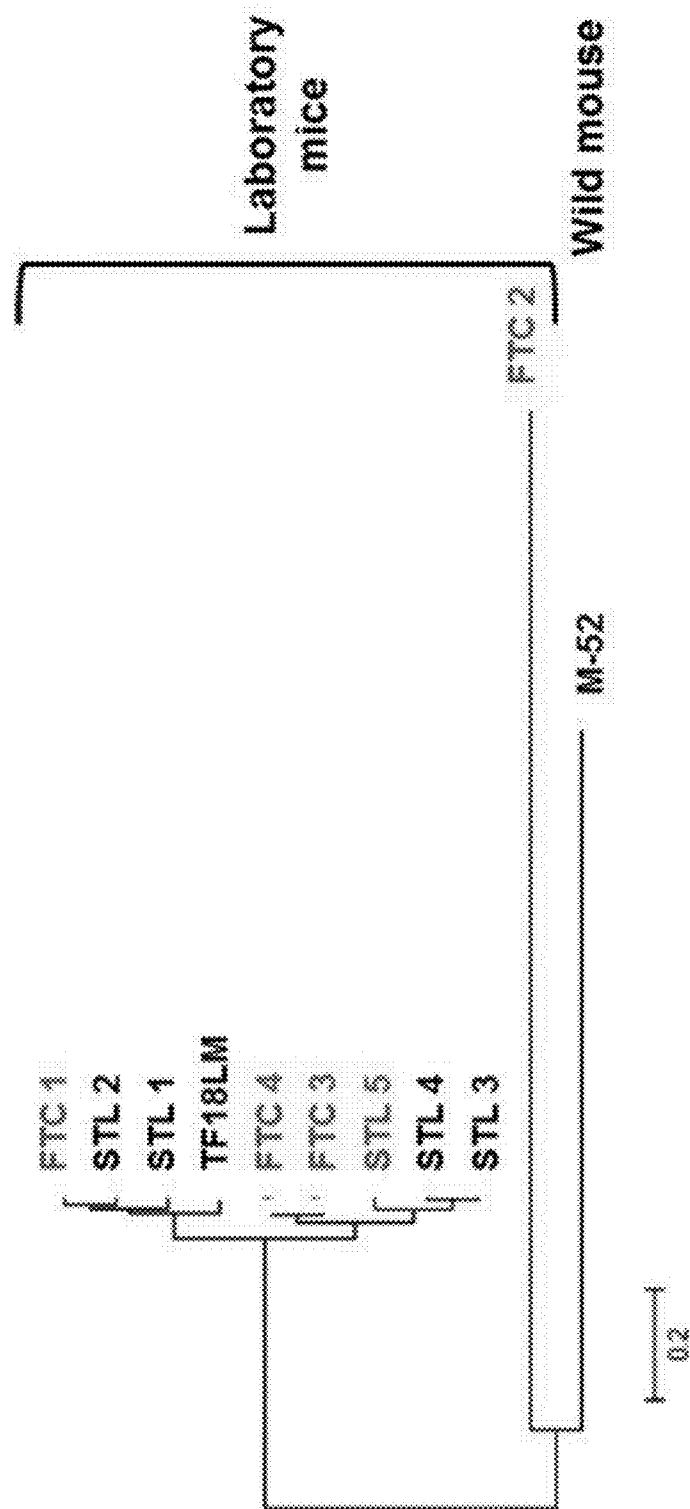


FIG. 8

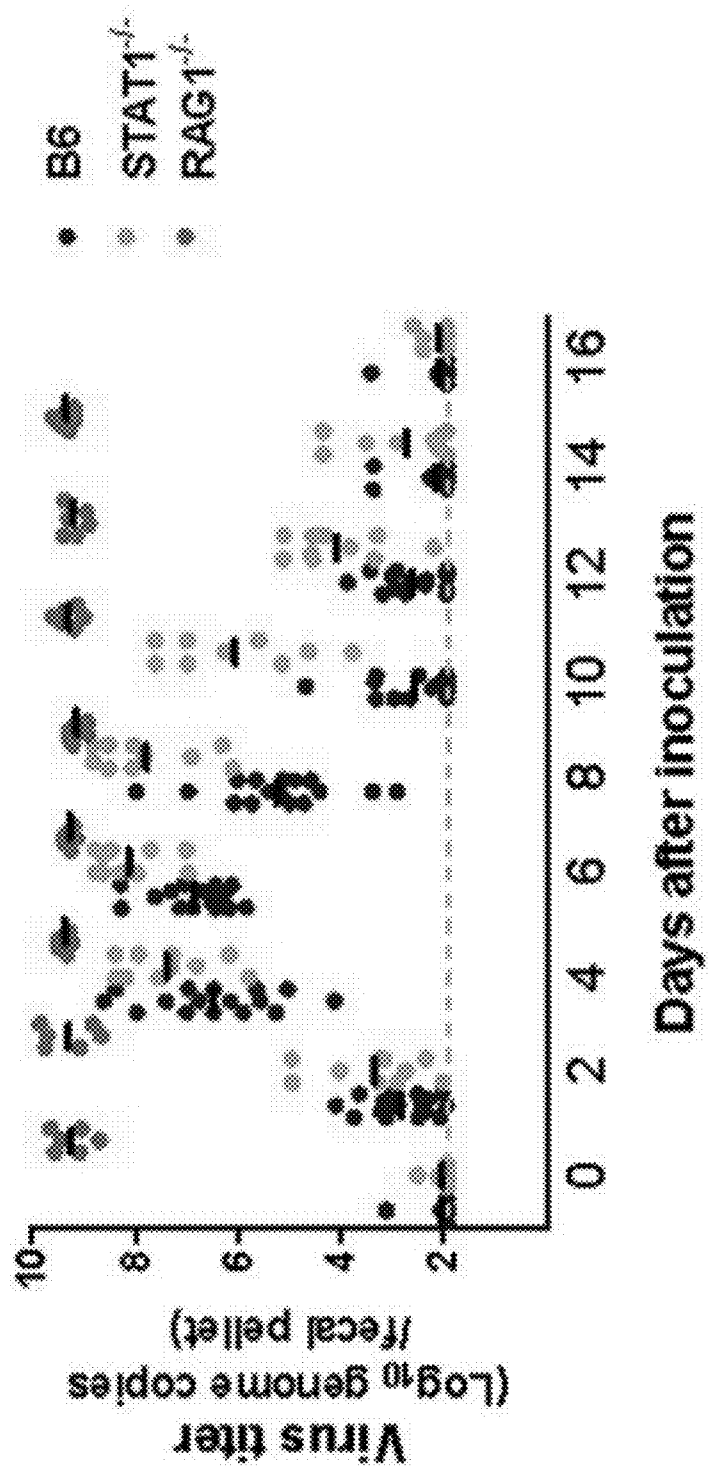


FIG. 9

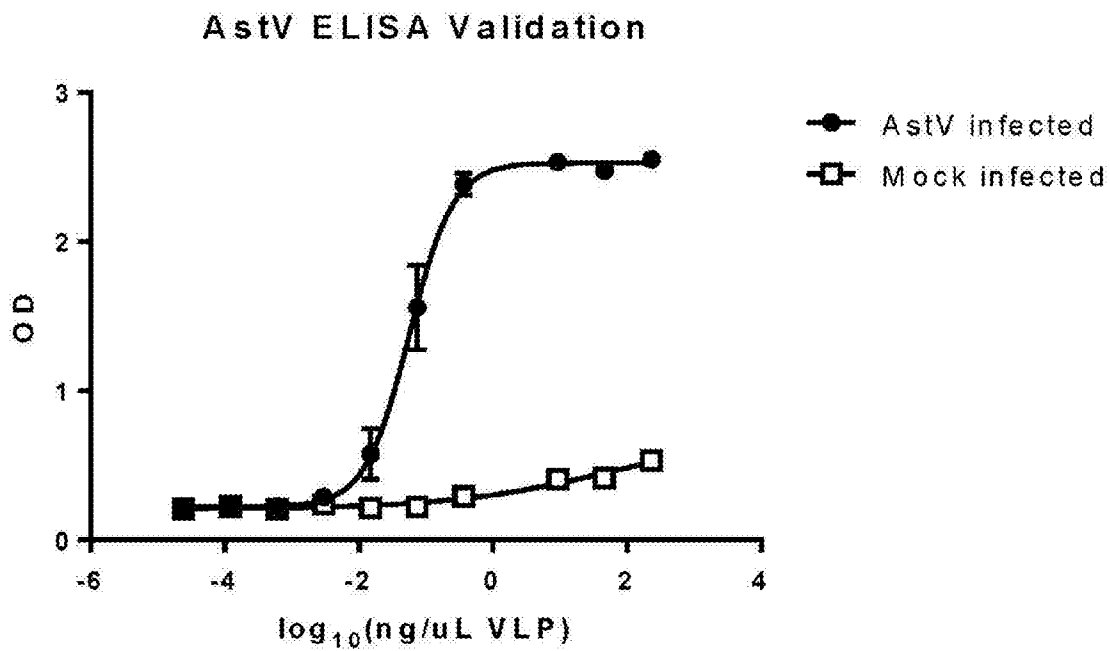


FIG. 10

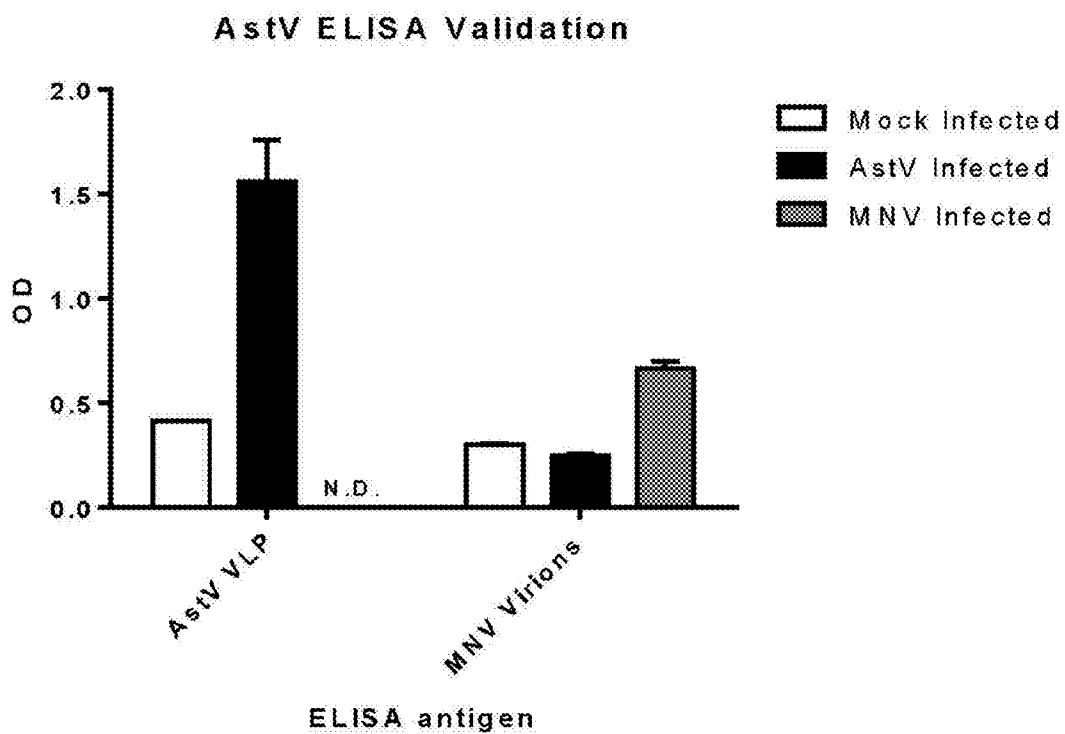
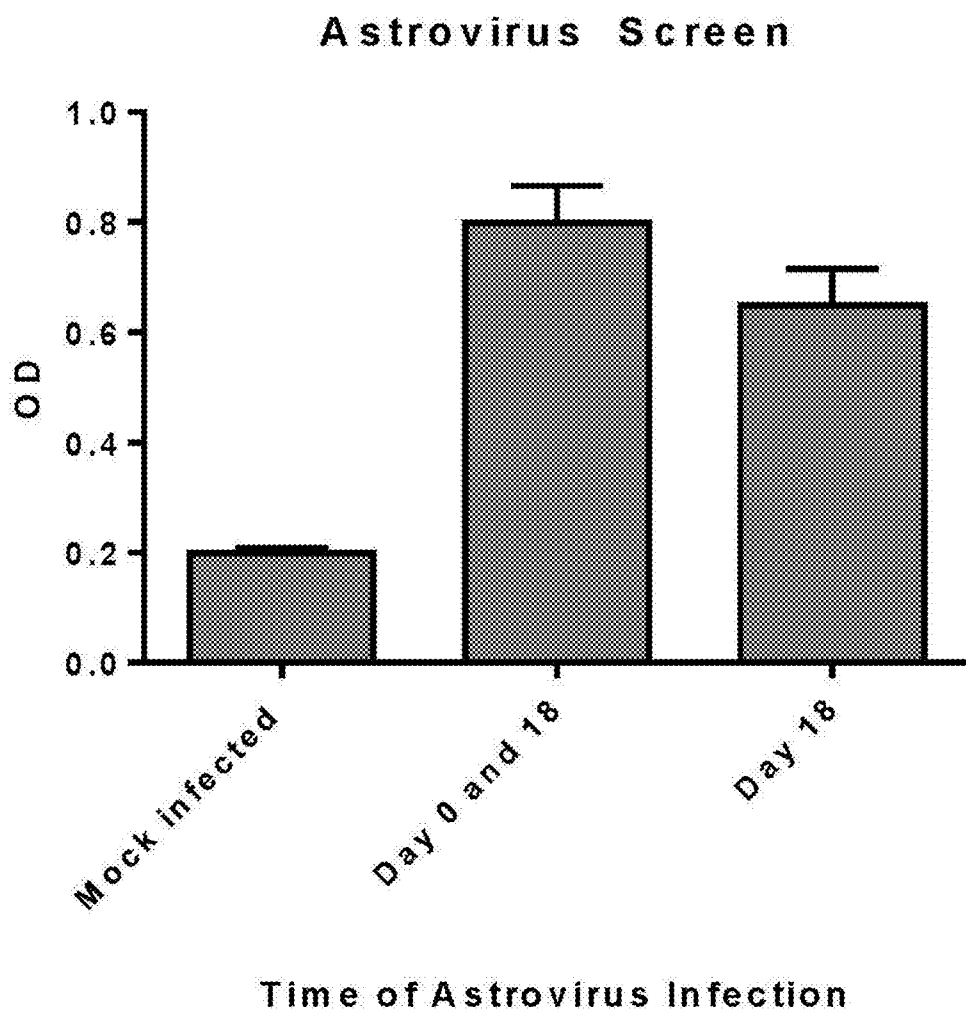


FIG. 11



MURINE ASTROVIRUSES

RELATED APPLICATION DATA

[0001] This application claims the benefit of U.S. Provisional Application No. 61/678,346, filed Aug. 1, 2012. The disclosure of U.S. Provisional Application No. 61/678,346 is incorporated herein by reference in its entirety.

GOVERNMENT RIGHTS

[0002] This invention was made with the support of Grants RO1 AI054483-09, U54 AI057160-08, R01 AI084887-02 from the National Institutes of Health. The government of the United States of America may have certain rights in this work.

INCORPORATION BY REFERENCE OF SEQUENCE LISTING

[0003] The Sequence Listing, which is a part of the present disclosure, includes a computer readable form comprising nucleotide and amino acid sequences of the present invention submitted via EFS-Web. The subject matter of the Sequence Listing is incorporated herein by reference in its entirety.

INTRODUCTION

[0004] Astroviruses are non-enveloped, positive-sense, poly-adenylated RNA viruses often associated with gastrointestinal disease (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). To date, astroviruses have been isolated from a number of hosts, including wild and domestic animals, marine mammals, birds, and humans, and new astrovirus-susceptible hosts continue to be identified (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Finkbeiner, S. R., et al., *Virology* 5: 117, 2008; Koci, M. D., et al., *J. Virol.* 74: 6173-7, 2000; Li, L., et al., *J. Virol.* 85: 9909-17, 2011; Phan, T. G., et al., *PLoS Pathog.* 7: e1002218, 2011; Reuter, G., et al., *Arch. Virol.* 156: 125-8, 2011). The Human astroviruses (HAsV) in particular are an important cause of gastroenteritis in inpatient and outpatient pediatric, HIV-infected and immunocompromised, and elderly populations, and have been shown to cause sporadic outbreaks of gastroenteritis in immunocompetent adults as well (Belliot, G., et al., *J. Med. Virol.* 51:101-6, 1997; Coppo, P., et al., *Ann. Hematol.* 79:43-5, 2000; Cunliffe, N. A., et al., *J. Med. Virol.* 67: 563-6, 2002; Dennehy, P. H., et al., *J. Infect. Dis.* 184: 10-5, 2001; Finkbeiner, S. R., et al., *J. Virol.* 83: 10836-9, 2009; Gray, J. J., et al., *J. Med. Virol.* 23: 377-81, 1987; Grohmann, G. S., et al., *N. Engl. J. Med.* 329: 14-20, 1993; Herrmann, J. E., et al., *N. Engl. J. Med.* 324: 1757-60, 1991; Jeong, H. S., et al., *Korean. J. Peds.* 55: 77-82, 2012; Lewis, D. C., et al., *J. Hosp. Infect.* 14: 9-14, 1989; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007; Oishi, I., et al., *J. Infect. Dis.* 170: 439-43; Palombo, E. A. and Bishop, R. F., *J. Clin. Microbiol.* 34: 1750-3, 1996; Shastri, S., et al., *J. Clin. Microbiol.* 36: 2571-4, 1998; Wood, D. J., et al., *J. Med. Virol.* 24:435-44, 1988). As a viral agent of pediatric diarrhea, astrovirus is reportedly second only to rotavirus (Dennehy, P. H., et al., *J. Infect. Dis.* 184: 10-5, 2001; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007), with a seroprevalence of neutralizing antibodies to Human Astrovirus (HAsV) 1 nearing 90% by the age of 9 (Koopmans, M. P., et al., *Clin. Diagn. Lab. Immun.* 5: 33-7, 1998). Furthermore, given the incorporation of rotavirus vaccines into national immunization programs (Patel, M. M., et

al., *Lancet. Infect. Dis.* 12: 561-70, 2012), the proportion of astrovirus-mediated diarrhea is likely to increase.

[0005] However, astrovirus disease is not limited only to the gastrointestinal tract. Astroviruses have been implicated as the cause of hepatitis in ducks and neurological disease in minks (Blomström, A. L., et al., *J. Clin. Microbiol.* 48: 4392-6, 2010; Gough, R. E., et al., *Avian. Pathol.* 14: 227-36, 1985). In humans, an astrovirus was identified as the cause of encephalitis in an immunocompromised child with X-linked agammaglobulinemia (Quan, P. L., et al., *Emerg. Infect. Dis.* 16: 918-25, 2010). Furthermore, we have previously reported the presence of the human astrovirus MLB2 in the plasma of a febrile child (Holtz, L. R., et al. *Emerg. Infect. Dis.* 17: 2050-2, 2011).

[0006] The Astroviridae family is divided into the mamastrovirus and avastrovirus genera-characterized by the ability to infect mammals and avian species, respectively. Across both genera, the astrovirus genome ranges from 6.1 to 7.7 kilobases (kB) in length, not including the 3'-polyadenylated tail, and contains three open reading frames (ORFs) and 5' and 3' untranslated regions (UTRs) (Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). ORF1a encodes a polypeptide of 920-935 amino acids (aa) in length containing conserved motifs, including a serine protease (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). A highly conserved heptanucleotide motif and downstream hairpin structure at the ORF1a/ORF1b junction generates a-1 frameshift (Jiang, B., et al., *P. Natl. Acad. Sci. USA.* 90: 10539-43, 1993; Lewis, T. L. and Matsui, S. M., *Arch. Virol.* 140: 1127-35, 1995) to lead to the translation of an ORF1a/1b polypeptide which is later cleaved into polypeptides corresponding to ORF1a and ORF1b (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). ORF1b encodes a polypeptide of approximately 515-528 aa which contains the RNA-dependent RNA polymerase (Lewis, T. L., et al., *J. Virol.* 68: 77-83, 1994; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). ORF2 encodes a 672-816 aa polypeptide which encodes the viral structural proteins including the capsid (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Lewis, T. L., et al., *J. Virol.* 68: 77-83, 1994; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007).

[0007] Despite the prevalence of astrovirus infection and the potential for extra-intestinal disease, there are no specific treatment protocols for astrovirus infection, and no vaccine exists. To date, little is known about the molecular mechanisms of astrovirus infection, replication, and disease pathogenesis, in part due to the lack of a genetically manipulable small animal model. Astroviruses have been identified as pathogens in humans as well as in a wide variety of non-human animals. Thus, it would be desirable to develop new approaches for treating or preventing diseases caused by astroviruses. This can be achieved by the development and testing of new vaccines and pharmaceutical agents using small animal models of astroviral diseases.

SUMMARY

[0008] The present inventors have utilized next generation sequencing (NGS) in combination with sequence analysis software (the pipeline VirusHunter software package) to identify a number of novel human astroviruses by analyzing the nucleic acid sequences generated by the Roche/454 next-

generation sequencing platform (Voelkerding, K. V. et al., *Clinical Chemistry* 55: 641-658, 2009) or by Sanger sequencing (Sanger, F., et al., *Proc. Nat'l. Acad. Sci. USA* 74: 5463-5467, 1978) and their predicted translation products (Finkbeiner, S. R., et al., *J. Virol.* 83: 10836-9, 2009; Finkbeiner, S. R., et al., *J. Virol.* 5: 117, 2008; Finkbeiner, S. R., et al., *J. Virol.* 6:161, 2009). Whereas previous work in our lab identified murine norovirus as a common pathogen found in research mice, we applied our custom pipeline to further analyze the enteric virome of the research mouse (Karst, S. M., et al., *Science*. 299:1575-8, 2003; Thackray, L. B., et al., *J. Virol.* 81:10460-73, 2007; Wobus, C. E., et al., *J. Virol.* 80: 5104-12, 2006).

[0009] The present inventors have established that astrovirus can infect rodents such as, without limitation, laboratory mice. Accordingly, the present disclosure relates to methods of detecting astrovirus in mammals, in particular murine astrovirus in mice.

[0010] In various aspects, the present teachings can comprise methods of monitoring astrovirus infection in a population of mice, such as, in non-limiting example, in a colony of laboratory mice. The methods can comprise detecting a murine astrovirus antigen or nucleic acid in one or more animals housed in a colony.

[0011] In various embodiments of the present teachings, murine astroviruses can provide an animal model for developing and testing vaccines vaccination protocols, pharmaceutical agents, and therapeutic treatment protocols to prevent and/or treat diseases caused by astroviruses or linked to astrovirus infection. In various embodiments, the animal model can be a murine model. Because related astroviruses infect humans, a murine astrovirus model of infection can serve as a model system for developing vaccines and therapeutics that could be effective in preventing or treating human astrovirus-linked diseases, or astrovirus-linked diseases in non-human animals.

[0012] Thus, one embodiment can involve the use of mice that are infected with astroviruses. Any of a variety of strains of mice can be used. The present studies have shown that adaptive immunity is essential for restricting astrovirus replication as has also been shown to be the case in humans (Wood, D. J., et al., *J. Med. Virol.* 24:435-44, 1988). Thus, in certain embodiments, the murine model can include mice that are immunocompromised such as B-cell deficient mice (MuMT) or RAG deficient mice (RAG1^{-/-}).

[0013] In some aspects, the present teachings include selecting, monitoring, or modifying a treatment on the basis of the detection of the presence, absence or quantity of astrovirus in a subject. In these aspects, the detection of the presence, absence or quantity of astrovirus in a subject can comprise detection of astrovirus in a sample from the subject.

[0014] In some aspects, the present teachings include detection of a murine astrovirus using one or more nucleic acid probes. A probe of these aspects can comprise, consist essentially of, or consist of a sequence having at least 70% sequence identity with a sequence of a murine astrovirus nucleic acid, or a complement thereof. In various configurations, a sequence having at least 70% sequence identity with a sequence of a murine astrovirus nucleic acid, or a complement thereof, can have at least 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity with a murine astrovirus nucleic acid, or a complement thereof. In

various embodiments, a nucleic acid of the present teachings can be at least 10 nucleotides in length up to about 100 nucleotides in length.

[0015] In various embodiments, detection of a murine astrovirus can comprise a hybridization assay using a nucleic acid probe that hybridizes to a murine astroviral nucleic acid sequence under stringent conditions.

[0016] In various embodiments, detection of the astrovirus can involve the use of one or more nucleic acid probes including hybridization assays using a nucleic acid probe that hybridizes to a murine astroviral nucleic acid sequence under stringent conditions. Hybridization assays can include a southern blot, a northern blot, a dot blot, or a slot blot. In some aspects, murine astrovirus can be detected using a PCR assay such as an RT-PCR assay or a quantitative RT-PCR assay, or a sequencing-based assay such as a pyrosequencing assay.

[0017] In some embodiments, presence, absence, or quantity of astrovirus can be measured using an antibody probe that binds an astrovirus antigen to form an immune complex which can then be detected as to presence, absence or quantity of an immune complex.

[0018] In various embodiments, detecting a murine astrovirus in a subject can comprise a) providing a biological sample from the subject; b) contacting the sample with at least one antibody probe that binds at least one murine astrovirus antigen under conditions sufficient for formation of an immune complex comprising the at least one probe and the at least one astrovirus antigen if present; and c) detecting presence, absence or quantity of an immune complex comprising the at least one probe and the at least one astrovirus antigen. In these embodiments, a sample can comprise astrovirus, or can be suspected of comprising astrovirus. An antibody probe can be a monoclonal or polyclonal antibody, or a portion thereof such as a Fab fragment. In some aspects, a murine astrovirus antigen can be a capsid protein or a portion thereof, or any other protein encoded by a murine astrovirus ORF, or a portion thereof. In some aspects, a murine astrovirus antigen can be immunologically cross-reactive with an astrovirus antigen hosted by another species. In various configurations, a murine astrovirus antigen of the present teachings can comprise, consist essentially of, or consist of at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14 or at least 15 contiguous amino acid residues of an astrovirus polypeptide. In various configurations, a murine astrovirus antigen of the present teachings can comprise, consist essentially of, or consist of a full length, isolated murine astrovirus polypeptide, such as, in non-limiting example, an astrovirus antigen such as a capsid protein that is expressed in a microorganism such as an *E. coli* or yeast, or in a mammalian, avian, or insect cell culture. In various configurations, a murine astrovirus antigen of the present teachings can comprise, consist essentially of, or consist of a murine astrovirus antigen of less than full length, such as, without limitation, an astrovirus antigen consisting essentially of or consisting of up to 100 amino acid residues, up to 90 amino acid residues, up to 80 amino acid residues, up to 70 amino acid residues, up to 60 amino acid residues, up to 50 amino acid residues, up to 40 amino acid residues, up to 30 amino acid residues, up to 25 amino acid residues, up to 20 amino acid residues, up to 15 amino acid residues or up to 10 amino acid residues.

[0019] In various embodiments, detection of astrovirus in a sample can comprise, without limitation, determining presence, absence or quantity of an antibody against astrovirus in

a subject. In some aspects, determining presence, absence or quantity of an antibody against astrovirus can comprise providing a sample from the subject; forming a mixture comprising a) the sample or antibodies comprised by the sample, and b) at least one astrovirus antigen, under conditions sufficient for formation of an antibody/antigen complex between the at least one astrovirus antigen and an anti-astrovirus antibody if present; and c) detecting presence, absence or quantity of an antibody/antigen complex.

[0020] In some aspects, methods disclosed in the present teachings comprise obtaining a sample from a subject, and detecting presence, absence or quantity of astrovirus in the sample. In various embodiments set forth herein, a sample from a subject can be a body fluid sample, such as, without limitation, a blood sample, a serum sample, a plasma sample, a cerebrospinal fluid sample, and/or a solid tissue sample. In some configurations, a blood sample can be a peripheral blood sample. In various configurations, a sample can comprise fibroblasts, endothelial cells, peripheral blood mononuclear cells, haematopoietic cells and various combinations thereof. In some embodiments, a sample can be a solid tissue sample, or a fecal (stool) sample. In some embodiments, a sample can comprise or can be suspected of comprising astrovirus.

[0021] In various aspects of these methods, detecting, diagnosing, monitoring or managing astrovirus in a subject can comprise providing a biological sample from the subject, and contacting the sample with at least one primary probe that binds at least one astrovirus antigen under conditions sufficient for formation of a probe/antigen complex between the at least one astrovirus antigen and the at least one probe, and detecting presence, absence or quantity of a complex comprising the at least one probe and the at least one astrovirus antigen. In some configurations, a probe that can bind a murine astrovirus antigen can be an antibody against a murine astrovirus antigen. In some embodiments, a primary probe can be any molecule that can bind a structure or antigen comprised by a murine astrovirus, such as an astrovirus protein or polypeptide, or an epitope thereof. In various configurations, the binding between a primary probe and a murine astrovirus structure or antigen can have a binding constant K_d of 10^{-5} or less, 10^{-6} or less, 10^{-7} or less, 10^{-8} or less, or 10^{-9} or less. In various embodiments, such primary probes can have high specificity, i.e., bind a murine astrovirus antigen with a binding constant less than that of a non-murine astrovirus antigen. Types of probes include, without limitation, an antibody, an antigen binding domain or antigen binding fragment of an antibody such as an Fab fragment, an aptamer (Jayasena, S. D., et al., *Clinical Chemistry* 45: 1628-1650, 1999), an avimer (Silverman, J., et al., *Nature Biotechnology* 23: 1556-1561, 2005) or any combination thereof. In various configurations, an antibody can be a monoclonal antibody, a polyclonal antibody or a combination thereof, and an aptamer can be an RNA aptamer, a DNA aptamer, a peptide aptamer, or a combination thereof. In various aspects, detection of binding of a probe to a polypeptide can comprise detecting a label bound directly or indirectly to the probe. A label can be any label known to skilled artisans, such as, for example, a radioisotope, a chromophore, a fluorophore, a quantum dot, an enzyme and a resonance light scattering (RLS) particle. In some configurations, an astrovirus antigen can comprise a contiguous sequence of at least 4 amino acids, at least 5 amino

acids, at least 6 amino acids, at least 7 amino acids, at least 8 amino acids, at least 9 amino acids, or at least 10 amino acids of an astrovirus polypeptide.

[0022] In some embodiments, the present teachings include an antibody against an astrovirus such as a murine astrovirus, and methods of generating such antibodies. In various configurations, these methods include providing an astrovirus antigen such as a capsid antigen, inoculating a host animal such as, in non-limiting example, a mouse, a hamster, a rat, a rabbit, or a bird (e.g. a chicken or duck), and collecting body fluid such as, for example, blood, plasma, serum, from the animal to obtain a polyclonal antiserum (or egg yolk from a bird to obtain an IgY antibody, see Schade, R., et al., *Altern. Lab Anim.* 33: 129-154, 2005). Alternatively, a monoclonal antibody against an astrovirus antigen such as a capsid protein can be generated using established methods (see, e.g. Kohler G, Milstein C., *Continuous cultures of fused cells secreting antibody of predefined specificity*, *Nature* 256: 495-497, 1975; Schreiber, R. D., et al., *J. Immunol.* 134: 1609-1618, 1985; Harlow, E., *Using Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1999). In various embodiments, an astrovirus itself can be a source of antigen. Alternatively, an astrovirus antigen can be an astrovirus protein expressed by recombinant means. For example, an astrovirus capsid protein or a portion thereof encoded by a plasmid vector can be expressed in a prokaryote such as *E. coli*, and the recombinant polypeptide can serve as antigen for generating an antibody.

[0023] In some configurations of the present teachings, detection of binding between the at least one antibody and at least one astrovirus antigen can comprise any binding detection method known to skilled artisans, such as, without limitation, an immunoprecipitation, a radioimmunoassay, a Western blot, an ELISA or a flow cytometry (FACS) assay.

[0024] Various configurations of the present teachings include methods of detecting, diagnosing, monitoring or managing an astrovirus infection or astrovirus-related disease. In various aspects, these methods comprise contacting a sample or antigens thereof with at least one probe that binds at least one astrovirus antigen under conditions sufficient for formation of a complex comprising the at least one probe and the at least one astrovirus antigen if present. In various configurations, the methods can comprise a) contacting a biological sample with a solid surface that binds at least one astrovirus antigen; and b) subsequent to a), contacting the surface with at least one probe. In some configurations of these aspects, the detecting presence, absence or quantity of a complex can comprise quantifying the at least one probe bound to the surface subsequent to b). In some configurations, the at least one probe can comprise a label, and the detecting presence, absence or quantity of a complex can comprise quantifying the label, which can be any label known to skilled artisans such as an enzyme, a radioisotope, a fluorogen, a fluorophore, a chromogen, or a chromophore.

[0025] In various embodiments, detection of binding between at least one probe directed against an astrovirus antigen, and an astrovirus or astrovirus antigen comprised by a sample can comprise direct detection, i.e., detection of a label comprised by the at least one probe, such as detection of a radioisotope or fluorophore comprised by the at least one antibody.

[0026] In various embodiments, detection of binding between at least one antibody directed against an astrovirus antigen (a "primary" antibody or probe), and an astrovirus or

astrovirus antigen comprised by a sample can comprise indirect detection, comprising detection of a label comprised by a secondary probe such as a secondary antibody directed against the primary antibody, a labeled avidin, a labeled streptavidin, or a labeled anti-biotin antibody for detection of a primary probe that is tagged with a biotin, or a labeled anti-digoxigenin antibody for detection of a primary probe that is tagged with a digoxigenin.

[0027] In various configurations, an antibody or probe of these aspects can further comprise one or more labels, such as an enzyme, a radioisotope, a fluorogen, a fluorophore, a chromogen, or a chromophore.

[0028] A radioisotope of the various configurations can be any radioisotope known to skilled artisans, such as, for example, ^3H , ^{14}C , ^{32}P , ^{33}P , ^{35}S , or ^{125}I .

[0029] A fluorophore of the various configurations can be any fluorophore known to skilled artisans, for example a fluorescein, a rhodamine, a coumarin, an indocyanine, or a green fluorescent protein (GFP).

[0030] An enzyme of the various configurations can be any enzyme for which a suitable substrate is available, such as, for example, alkaline phosphatase, a horseradish peroxidase or a chloramphenicol acetyltransferase. A suitable substrate is a substrate that, when contacted by an enzyme, produces a product that is detectable by methods known to skilled artisans. For example, the substrate can be a chromogenic substrate, such as, for example, p-dinitrophenyl phosphate as a substrate for alkaline phosphatase, or diaminobenzidine as a substrate for horseradish peroxidase. An enzyme substrate can alternatively be, in various configurations, a fluorogenic substrate, such as, for example, disodium 4-methylumbelliferyl phosphate substrate for alkaline phosphatase, or a chemiluminescent substrate, such as, for example, 5-amino-2,3-dihydrophthalazine-1,4-dione (luminol) for horseradish peroxidase, or disodium 3-(4-methoxyspiro{1,2-dioxetane-3,2'-(5'-chloro)tricyclo[3.3.1.1.3,7]decan}-4-yl)phenyl phosphate for alkaline phosphatase.

[0031] A hapten of the present teachings can be any hapten for which a probe is available. For example, the hapten can be a biotin, detectable with an avidin, a streptavidin, or an anti-biotin antibody, or a digoxigenin detectable with an anti-digoxigenin antibody, by methods well known to skilled artisans.

[0032] In various configurations, a sample can be a biological sample obtained from a subject, such as a biological fluid sample or a biological tissue sample. A biological fluid sample can be, without limitation, a blood sample such as a sample comprising peripheral blood mononuclear cells (PB-MCs), a plasma sample, a serum sample, a cerebrospinal fluid sample, a urine sample, or a saliva sample. A fluid sample can comprise cells, or can be cell-free. In some configurations, a fluid sample can be a peripheral blood sample. In some configurations, a sample can be a fecal (stool) sample.

[0033] In various configurations, a sample would be a cell culture sample, such as, for example, a culture supernatant from an astrovirus-infected culture, or a sample comprising cells from such a culture.

[0034] In various aspects of the methods, detecting astrovirus in a subject can comprise detecting presence, absence or quantity of antibodies against murine astrovirus in a sample from the subject, such as a fecal sample, a blood sample, a serum sample, a plasma sample, or a cerebrospinal fluid sample. These methods can include contacting a sample with a murine astrovirus or an astrovirus antigen such as, for

example a polypeptide component of an astrovirus or a peptide comprising an epitope of a murine astrovirus polypeptide, and detecting formation of a binding complex comprising antibody comprised by the sample and the astrovirus or astrovirus antigen. In some embodiments, a murine astrovirus or astrovirus antigen can be immobilized on a solid support. In some configurations, a solid support can be, without limitation, an ELISA plate, a bead, a dip stick, a test strip or a microarray.

[0035] In some configurations, methods of the present teachings can comprise providing a solid surface to which one or more antigens comprised by a sample are bound, contacting at least one probe to the solid surface under conditions sufficient for formation of a complex comprising at least one probe and one or more astrovirus antigens, and detecting presence, absence, or quantity of a complex comprising the at least one probe and at least one astrovirus antigen. In various configurations, the detecting can comprise an ELISA, a radio-immunoassay, a Western blot assay or a flow cytometry assay. In some embodiments, presence, absence or quantity of a complex comprising at least one astrovirus antigen and at least one probe can be determined by immunoprecipitation.

[0036] In various embodiments of the present teachings, the inventors disclose methods of detecting, diagnosing, monitoring or managing astrovirus in a subject in a seroconversion-type assay. In various aspects, these methods can comprise providing a sample from the subject, and forming a mixture comprising the sample and at least one murine astrovirus antigen under conditions sufficient for formation of an antibody/antigen complex between the at least one murine astrovirus antigen and an antibody, and detecting presence, absence or quantity of an antibody/antigen complex, wherein the sample comprises circulating antibodies from the subject. In various configurations, a sample can be a body fluid sample, such as a sample comprising circulating antibodies. In various configurations, a sample can be a blood sample, a plasma sample, a serum sample, a cerebrospinal fluid sample, a fecal (stool) sample or a combination thereof. In various aspects, detecting the presence, absence or quantity of an antibody/antigen complex can comprise contacting the mixture with at least one probe directed against a circulating antibody under conditions sufficient for formation of a probe/antibody complex; and detecting presence, absence or quantity of the probe. In some configurations, the probe can be directed against murine immunoglobulin, and can be, for example, an antibody, an antigen-binding fragment thereof, an aptamer or an avimer. In some configurations, the probe can comprise a label. In some configurations, the at least one astrovirus can be immobilized on a solid support.

[0037] In various embodiments of the present teachings, the inventors disclose vaccines against astrovirus infection. In these embodiments, a vaccine can comprise, consist essentially of, or consist of a murine astrovirus antigen, or a portion thereof. In some embodiments, a vaccine can comprise a vector comprising a murine astrovirus nucleic acid that encodes an entire open reading frame of a murine astrovirus polypeptide, or a portion thereof. A vector can be, for example, an adeno-associated virus (AAV) such as, without limitation, an AAV5 vector.

[0038] In various embodiments of the present teachings, the inventors disclose methods of testing vaccines and antiviral agents against astrovirus infection. In a typical protocol for a murine model, a vaccine or pharmaceutical agent would be administered to mice in a pre-treatment or treatment pro-

tocol, the mice would then be exposed to murine astrovirus through administration of the virus and/or through contact or co-housing with animals known to be infected with astrovirus. Outcomes of exposure would then be monitored.

[0039] In assessing a vaccine, the vaccine would be administered to infected mice and the effect of vaccination on the course of the infection monitored. Vaccine administration can be prior to administration of an astroviral challenge, at the about the same time or after administration of the astroviral challenge. The astroviral challenge can comprise, consist essentially of, or consist of administration of a preparation containing the astrovirus to one or more subject mice, exposure of a mouse or mice to an infected mouse or mice by co-housing or by any other suitable method that exposes an animal to the astrovirus.

[0040] A vaccine can comprise a murine astrovirus antigen, or a portion thereof. In some embodiments, the vaccine can comprise a vector comprising a murine astrovirus nucleic acid that encodes an entire open reading frame of a murine astrovirus polypeptide, or a portion thereof. A vector can be, for example, an adeno-associated virus such as, without limitation, an AAV5 vector.

[0041] In assessing a pharmaceutical agent, the agent can be administered after administration of the astroviral challenge. Any of a wide variety of agents can be tested in the model.

[0042] A candidate agent can be a candidate vaccine or a candidate pharmaceutical agent including synthetic, naturally occurring, or recombinantly produced molecules. Non-limiting examples include small molecules such as known anti-virals; drugs; peptides; antibodies (including antigen-binding antibody fragments, e.g., to provide for passive immunity) or other immunotherapeutic agents; endogenous factors present in eukaryotic or prokaryotic cells (e.g., polypeptides, plant extracts).

[0043] In various embodiments, candidate agents can encompass numerous chemical classes, though typically they are organic molecules, preferably small organic compounds having a molecular weight of more than 50 and less than about 2,500 Daltons. In some embodiments, candidate agents can comprise functional groups necessary for structural interaction with proteins, for example hydrogen bonding, and can include, for example, an amine, a carbonyl, a hydroxyl or a carboxyl group, preferably at least two functional chemical groups. In some configurations, a candidate agent can comprise cyclical carbon or heterocyclic structures and/or aromatic or polyaromatic structures substituted with one or more of the above functional groups.

[0044] Candidate agents can also be found among biomolecules including, but not limited to: peptides, saccharides, fatty acids, steroids, purines, pyrimidines, derivatives thereof, structural analogs thereof or combinations thereof.

[0045] Candidate agents can be obtained from a wide variety of sources including libraries of synthetic or natural compounds. For example, numerous means are available for random and directed synthesis of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides and oligopeptides. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant and animal extracts are available or readily produced. Additionally, natural or synthetically produced libraries and compounds are readily modified through conventional chemical, physical and biochemical means, and can be used to produce combinatorial libraries. Known pharmacological

agents can be subjected to directed or random chemical modifications, such as acylation, alkylation, esterification, amidification, etc. to produce structural analogs.

[0046] The outcome of infection can be monitored by any of a variety of methods including detection the presence, absence or quantity of astrovirus in a sample from an infected mouse, measuring immunochemistry aspects such as antibody produced in response to infection, detecting any symptomatology or any other suitable method.

[0047] The present teachings include, without limitation, the following aspects:

1. An isolated polynucleotide comprising, consisting essentially of, or consisting of a nucleotide sequence that is at least 70% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4, and wherein a virus comprising said polynucleotide is infectious towards a mammal.
2. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is at least 75% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4
3. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is at least 80% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
4. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is at least 85% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
5. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is at least 90% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
6. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is at least 95% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
7. An isolated polynucleotide in accordance with aspect 1, wherein the nucleotide sequence is 100% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
8. An isolated polynucleotide in accordance with aspect 1, wherein the mammal is a primate.
9. An isolated polynucleotide in accordance with aspect 1, wherein the primate is a human.
10. An isolated polynucleotide in accordance with aspect 1, wherein the mammal is a rodent.
11. An isolated polynucleotide in accordance with aspect 10, wherein the rodent is a mouse.
12. An oligonucleotide comprising, consisting essentially of, or consisting of a sequence consisting of about 10, from 10 to 70, or about 70 nucleotides, wherein said oligonucleotide hybridizes to a nucleic acid of a murine astrovirus or the complement thereof under high stringency conditions (Sambrook, J., et al., *Molecular Cloning: A Laboratory Manual*, 3rd ed. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2001; Ausubel, F. M., et al., ed., *Current Protocols in Molecular Biology*, Wiley Interscience, 2003).
13. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of about 10, from 10 to 60, or about 60 nucleotides.

14. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of about 10, from 10 to 50, or about 50 nucleotides.

15. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of about 10, from 10 to 40, or about 40 nucleotides.

16. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide probe comprises, consists essentially of, or consists of a sequence consisting of about 10, from 10 to 30, or about 30 nucleotides.

17. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide probe comprises, consists essentially of, or consists of a sequence consisting of about 10, from 10 to 20, or about 20 nucleotides.

18. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of about 15, from 15 to 60, or about 60 nucleotides.

19. An oligonucleotide in accordance with aspect 12, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of about 20, from 20 to 60, or about 60 nucleotides.

20. An oligonucleotide selected from the group consisting of

CCAAGAAAGAGGGCACTAGTGGCACTC; (SEQ ID NO: 6)

GTTTTTTTTTTTTTTTTTTTTTTTGCCAATTTTATGCCAATTATATCACC
C; (SEQ ID NO: 7)

TACATCGAGCGGGTGGTCGC; (SEQ ID NO: 8)

GTGTCACTAACGCGCACCTTTTCA;
and (SEQ ID NO: 9)

TTTGGCATGTGGGTAA. (SEQ ID NO: 10)

21. A nucleic acid-based vaccine, comprising a vector comprising a murine astrovirus sequence encoding an astrovirus polypeptide or a portion thereof, wherein the vector is other than a murine astrovirus.

22. A method of detecting presence, absence or quantity of a murine astrovirus in a biological sample, the method comprising:

[0048] providing a sample comprising or suspected of comprising an astrovirus;

[0049] contacting the sample with at least one nucleic acid that is complementary to a nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, under hybridization conditions; and

[0050] detecting the presence, absence or quantity of a hybrid nucleic acid comprising the probe and the astrovirus nucleic acid.

23. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or

the complement thereof, has at least 75% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

24. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 80% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

25. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 85% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

26. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 90% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

27. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 95% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

28. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 22, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has 100% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

29. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with any one of aspects 22-28, wherein the detecting comprises a quantitative PCR assay.

30. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with aspect 29, wherein the quantitative PCR assay is a quantitative RT-PCR assay.

31. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with any one of aspects 22-28, wherein the detecting comprises a pyrosequencing assay.

32. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with any one of aspects 22-28, wherein the detecting comprises a hybridization assay selected from the group consisting of a southern blot, a northern blot, a dot blot, and a slot blot, and a RACE assay.

33. A method according to any one of aspects 22-32, wherein the diagnostic sample is selected from the group consisting of a fecal sample, a vomitus sample, a tissue sample and a blood sample.

[0051] 34. An isolated polypeptide comprising, consisting essentially of, or consisting an amino acid sequence at least 70% identical to at least 4 contiguous amino acids of a polypeptide encoded by an open reading frame comprised

- by a nucleotide sequence selected from the group consisting of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
35. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is at least 75% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
36. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is at least 80% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
37. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is at least 85% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
38. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is at least 90% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
39. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is at least 95% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
40. An isolated polypeptide in accordance with aspect 34, wherein the nucleotide sequence is 100% identical to any one of SEQ ID NO:1, SEQ ID NO:2, SEQ ID NO:3, and SEQ ID NO:4.
41. An isolated polypeptide in accordance with aspect 34, wherein the mammal is a primate.
42. An isolated polypeptide in accordance with aspect 41, wherein the primate is a human.
43. An isolated polypeptide in accordance with aspect 34, wherein the mammal is a rodent.
44. An isolated polypeptide in accordance with aspect 45, wherein the rodent is a mouse.
45. An oligopeptide comprising, consisting essentially of, or consisting of at least 4 up to 60, or about 60 amino acid residues of a murine astrovirus antigen.
46. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 50, or about 50 amino acid residues.
47. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 40, or about 40 amino acid residues.
- [0052] 48. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 30, or about 30 amino acid residues.
49. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 20, or to about 20 amino acid residues.
50. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 15, or about 15 amino acid residues.
51. An oligopeptide in accordance with aspect 45, wherein the oligopeptide comprises, consists essentially of, or consists of up to 10, or about 10 amino acid residues.
52. An oligopeptide in accordance with any one of aspects 34-51, further comprising a label.
53. An oligopeptide in accordance with aspect 52, wherein the label is selected from the group consisting of a fluorophore, a hapten, an enzyme and a radioisotope.
54. An antibody directed against a polypeptide or oligopeptide of any one of aspects 34-51.
55. A method of detecting presence, absence or quantity of an astrovirus in a biological sample, comprising performing a virus detection assay selected from the group consisting of a cytopathic assay, an antibody assay and a protein detection assay.
56. A method according to aspect 55, wherein the cytopathic assay is selected from the group consisting of a dye exclusion assay, an enzyme release assay and an apoptosis assay.
57. A method according to aspect 55, wherein the antibody assay is selected from the group consisting of a Western blot assay, an ELISA assay, an immunofluorescence assay, an immunoprecipitation assay and a radioimmunoassay.
58. A seroconversion assay for detecting a murine astrovirus in a murine subject, comprising:
- [0053] providing a serum or plasma sample from a subject;
 - [0054] contacting the sample with an oligopeptide of any one of aspects 45-53; and
 - [0055] detecting presence, absence or quantity of a complex comprising the oligopeptide and antibody that binds the oligopeptide.
59. A method for screening a candidate agent for anti-viral activity against an astrovirus, the method comprising:
- a) providing a mouse susceptible to a disease or condition caused by the astrovirus;
 - b) infecting the mouse with the astrovirus;
 - c) administering the candidate agent to the mammal; and
 - d) monitoring indices of infection wherein decreased indices of infection indicates anti-viral activity against the astrovirus.
60. A method according to aspect 59, wherein the astrovirus is MoAstV.
61. A method according to aspect 59, wherein the candidate agent is a vaccine.
62. A method according to aspect 59, wherein the candidate agent is pharmaceutical agent.
63. A method according to aspect 59, wherein the mouse is an immunocompromised mouse.
64. A method according to aspect 60, wherein the mouse is a MuMT or RAG1^{-/-} mouse.
65. A method according to aspect 59, wherein the monitoring comprises detecting presence, absence or quantity of an astrovirus in a biological sample obtained from the mouse by performing a virus detection assay according to any one of aspects 22-33 or 55-57 wherein absence or decreased quantity of astrovirus indicates antiviral activity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] FIG. 1 illustrates a comparison between identified astrovirus sequences.

[0057] FIG. 2 illustrates a schematic of the identified astrovirus genomes.

[0058] FIG. 3 illustrates detection of astrovirus in immunocompromised mice by PCR.

[0059] FIG. 4 illustrates that adaptive immune response is required to control astrovirus replication.

[0060] FIG. 5 illustrates that astrovirus can be detected in commercially available mice.

[0061] FIG. 6 illustrates antibody responses during murine astrovirus infection.

[0062] FIG. 7 illustrates genetic diversity of murine astroviruses identified by next generation sequencing.

[0063] FIG. 8 illustrates kinetics of murine astrovirus shedding.

[0064] FIG. 9 illustrates an AstV (astrovirus virus-like particles) ELISA validation.

[0065] FIG. 10 illustrates a second AstV (astrovirus virus-like particles) ELISA validation.

[0066] FIG. 11 illustrates an AstV (astrovirus virus-like particles) ELISA screen.

DETAILED DESCRIPTION

Methods

[0067] Methods and compositions described herein utilize laboratory techniques well known to skilled artisans. Such methods and compositions can be found described in laboratory manuals such as Sambrook, J., et al., *Molecular Cloning: A Laboratory Manual*, 3rd ed. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2001; Spector, D. L. et al., *Cells: A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1998; Harlow, E., *Using Antibodies: A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1999; Ausubel, F. M., et al., ed., *Current Protocols in Molecular Biology*, Wiley Interscience, 2003; Nagy, A., et al., *Manipulating the*

Mouse Embryo: A Laboratory Manual (Third Edition), Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2003. Methods of administration of pharmaceuticals and dosage regimes, can be determined according to standard principles of pharmacology well known skilled artisans, using methods provided by standard reference texts such as Remington: *the Science and Practice of Pharmacy* (Alfonso R. Gennaro ed. 19th ed. 1995); Hardman, J. G., et al., *Goodman & Gilman's The Pharmacological Basis of Therapeutics*, Ninth Edition, McGraw-Hill, 1996; and Rowe, R. C., et al., *Handbook of Pharmaceutical Excipients*, Fourth Edition, Pharmaceutical Press, 2003. These publications are incorporated herein by reference, each in its entirety.

[0068] As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context indicates otherwise. Examples presented herein are illustrative and are not intended to be limiting to the scope of any claim.

[0069] Sequences of murine astroviruses of the present teachings include the following:

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>Mouse_Astrovirus_STL_CY1_20120531_Update
                                     (SEQ ID NO: 1)
CCAAGAAAGAGGGCACUAGUGGCACUCCUGCUGCUAGUAAGUCUGACAUGGCCUCUG
CGUAAGGAGUAUACUUCUCCUUGUGGACCAAGCGGUCGACGCUGGGAAUUACCCUG
GCCCGUCGCCAGUUGCCAACUACGGCAAUUCUGCUGCGCAAUUGCCUGACC
ACUAUCCUAACCGGCCUUGGUCUGUCCAUUCGACCCCCGCCAAUUGGUCUAUCC
CUCAACAAACGGGAUGAUCCAAAGACGCGGGUUAUACAGCCUCCUCCGUCACAGUG
GAGGAUGAAUGGGUGACCUAUGUCUGGACCGGCGCGCUGGCAGCAGGUGGCA
ACGGCCCCUGACUGUGGAAAAACGAUCCUGGUCUGUGCCUCCUGAACGAACAUA
AGCGGCUCAAGGAUGAGAAUGCAAGCCUUAACUUGCCAAGGCGAAUUGGAGG
UUGUAUACACACACUGCGGGUGGCGUCAGCGGCCAUUACCAACUCGGCCCCUCG
CCGUUCGCGCCUCCUUGGAUCCUGGCACUCUUGGCUGUGCUUUUUCUCCUCCUC
ACGACCUCGGCUGCCUUUGAAACCAGCUCUACCUACGGAGCUAUGCCCCUGAGG
AUAUUGCUAGGCACUCUGAGGAUUUGAACACCUUUUAUUGAGAACGCUUUGAGGG
UGAACCAACACACGCUCUACACAGAGUACACCUAACCAACUGUACGCCACACAUUG
UCAGACUUUCUUGGACCGCAUUGGCCUUGACAUUUAACACUUGGCAAGCUUAUGAU
CCGCACUUUUUGCGAAAACACCCUUGCAAGUGCGCUUCUGAGUGUCCUCCAGU
AUGUAACACCCUGGACGUGGGAGAUAGCCUUACGGGCUGGUUUUGGCGCUCA
UGCUAGCGGAAAACUCUAGCCUUGGUUGGUCUGUCUACCUUGGCCUGUGCUACUCU
CACAAAGGACCCGCUUUGCCUUCUUGGCCGUGGCGCCUUCAGACACGCUACAGC
ACGGCUGUCACCGUUGCCGCCUUGGUCUCUACGCACUCGACCCUUGGUCGCAG
UGGCUGGCCUGGUGCUACACCUUUUCUUGGCAGUGGUGGGGCUUUCAUGGA
GGAUACCUCCUUAUGUCCAAAACUUGAAGGGCGCCUUCUGCUGCUAUGGCCUUC
UUCGGCCAUGCCUUCUGGCCUUCUUGGAGUGAGCUCGGCGCCAGUCACAACAC
UAGCUUUGCCUGGCGGAUCUGGCGGCUACUCUCUGGCGGAAACAGGCAC
CGUGGAGGUGCGCAAUGAAGAAGGCAAGGUGGUCUAAAACAGACCACGCAACCC
AACUUCUUCUUCGCUUCAAGCAGGCGUUGAGGAGGAUGAGACAACUCAGAACGA
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CCCAGACCCCCUAGCGCGGUCAAUCCUGAUGCGCUCUGCCACAUCAGCGUGGC
CGGGGCGAAAGGCACUGGCUUUUUUGUGGUAACUACGCUGUGACAUUGGCACA
CGUAGUCGGGAGUGAGACAGUCGUCAAACCUUGUCUAUAAAGGCCGUAACUAUCA
GGCCCCAGUGAAGAAAUCUUGGAGCAAAAGGAUGUGGCACUCAUUCUCAUACCU
GCGGGUAUAAACACCCCGCUUAGAAGUCCCAAGAGCACUGCUGGCACUGGG
UCUGUGUCUGGCCCCGACGGUGAUGGUGCCUACCUAACUGCUGUGACUGAGG
UUGCGAGCAUGAUGGUCACUACUCUAUGCCUGCCGACGCGGGGAUGGGAUGUCU
GGCGCCUCUGUUAGACAUAGAUGGCCAUGUUCUUGGGUAACACACUAACAACA
CUGGCUACACUGGUGGUGCCCAACGCCUCGACCUUGAGGCAUAGUUGAAGCCCC
CAAGCCAAAUCCCAAGCAGCUCGCCCCGAGAGGGAGAUUGAAGAACUGAAAAG
CAGCUUGCGGCCUCGACCCUGAACCAACCUAGGCCUGAGCCGUGGCUGCCCCUC
CCUACCCGUUCAGCCCGGCCCCUAGUGGUUCCAACUACCUGCCCCUCAGCC
CCACCGGCACCAACUGUGGCCCCUGCUCUUGUGGCCCCAGCCUCUGGGCGCACU
AUGUGGUCAAACCCACCAAUCCACCUAUGCAACAAGCCUAACAACUAGUGA
UGUGGUUGAUCUUGUGCGUGCGGCAAUGGGUCGUGAGAUCAAUCCUGCGGGA
CGAGCUGAACUGAUGAAUCAGGCUAAGGGGAAGACCAACGUGGCCGUGGGAA
GAAGCAUACCAUCGGGGCUCGUGUUGUGGCCGUCGACAGCAGCGUGGCCUGCC
UUCACCGAGGAGGAGUACAAGGAGUUGGACCAAGGGAUUGACCCCGAUGAG
AUCAAGCGCCUAGCCGAAGACCUUGGGAGGACCAGACUGGCUCUCCGGAGUGGA
GUGACCUGAGUUCUCUGAUGAGGACGAUGGUUGGACACCAAGACCAUGACU
GGCUAGACUUUGAUUAUGAGGAGAUUAUUGGAACAAACUACGUCCCIUGGUCCU
GGGCCAGAAAUGCAAGAUACCUUCGUGGACUACGUCAGAAGAUCUUUGACAA
AGGCUCCGUUGAUGAGAUUUAACAAAUCUUGCCCCUCUGGAGAAGAAGCUCUG
UAGGAAACAACUUGAGGCCGUUCGCCAGGCAAAAACUGAUUACGAGCUCUCUGU
UGCACUUGGCUCUUGGAUCGUCGUGCUGCCGAGUGGGCAUGCAGCCUUUACA
CCAGGGCUAGAGUAUAAACAAGCUGUUCAAAAAAGCCCAAGGGCCCCGCAAGG
GGCAAAAGAUACGGGCUCGAAGACUGGAAAGAACUAAGGCAGCCCCCUUUCG
CUCUGGUACCCAGCCUUAACCUUGUUGUCUGCAGCUUACCCUGGACCGGCCCA
UCUAUGACAACGAUGAGCCUAAGAUCACUUCUGGGGGUGUUGCCACAUGUAG
ACUAUGAGGGUAACUUUGCACCAACAACCUUGGGAGGCGCAGCUUACGGAAGA
GUUUCGAGAAGUACGUAUGCUAACCUUGGACUUCGAAAAGCACUAUCUG
UAGAAACUCAGUUCGUGACUGGGCCUGGCAGUCCACACGCUUACUGGAAGG
CACUCGGUAUGCCACAUCAUGUCUACAGAGAAAAUACCGACUCAACCCUGCC
UACCCAAAUGCCUGGACUACUCCACCGAGGCCGACUACCUAGAGGAACAUGGCU
GGGAGCCCUAUGUCAACGCUUUCGUGCCAUGACUCCGGGGAGCGGCCCCAGGU
UCUCUGGUUCUCUUCUUGAAGAAGGAGAUUCUCAAACAAGAGAAGAUUCGCGA
UUCAGACAUUCGUCAGAUUGUCUGUUCAGAUCCAUUCUUGCGGGAUCGGAGCU
UGCUUCGAACAACAUCAAAACCAUCUAUGAAGCAAAAACAGAGACCAUUCGG
GGCAUUGUGCUGGUGCCCCUGAAGGGGGCUUUGAGGCAUUGGCCACCGUCU

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UGCCUCUAAGCAGGGUGUCUUUGUGGAAUUUGACUGGACACGCUUUGAUGGAAC
AAUCCCCGUACAACUCUUCGCGAGGAUAAAGAAGCUCGCGUGGUCCAUGAUUUUGU
CCCGAACAUACAGCAGCGCUACGGGCACAUGUACCAGUGGUUUGUUAACAUCUCU
UGCACCGCUACACCGUGCUGCCUCAGGUGAGGUGACCAUCCAAACUCGUGGCAA
CCCCUCAGGGCAAUUCUACAACAUAUGGAUAACAACAUGGUUAACUACUGGCUU
CAGGCAUUUGAGUUUCUGCUACUUCUUUGGCCUGAUAAAGAUCUCUGGCGGAG
UAUGAUACUGUCUGCUAUGGUGAUGACCGGCUUACGCGCUACCCUGUGCUACCAC
CCAUUAACAUCGAGCGGGUGGUCGCCAUGUACAAGGACAUUUUGGCAUGUGGG
UUA AACUGAAAAGGUGCGCGUUAGUGACACCCUGGUUGGUCACCCUUUUGUG
GCUUAGAAUAGGGGAGCACUAUUUGCCUAUCCUGCACAGGAAGACAAACUCU
UUGCCGGCCUCGUCGCGCCAGUGAGGAAUUGGCUAGCUUUAACAACUCUCAUGG
GAAAACUCUUGAGCCUGCAGCUUCUGAUGCACUUCACCCUCGAGUCUUUAAG
GACUACUUGGAGAUUGUCUUGGCAACACCCGCCAAGUACUGCCCGAACUUCGCG
CGCGUUUUACAGAGCGUCAGAUGGACAAGCUUUGGAGGGGAGGACCAAAGCUG
UUCAUGGCUAAGGCCAAACAACAAGAAAUGCCAGACCGUCACUACUACAA
CUGUACUUGGUCGCGAGUAGUCGGCGGUCUCGCGAGGCGCUCUGUACGGCGCGCGC
UGCAGGCCCUUCUAACCCCCAACAAAGACAACAACUGUUCGGACUGUUUUUCGC
CGCACUGCCCGGCCUCGCGGUGAUCGCGCGAGGAGUAGGAAUGCUCAGCGGAGG
CUCUCGCGAGGUUGUUACAGCGGUUACGGCGACCCUCGGAACGGUUGGCGCGAA
CCAGGGCAAUCAGGUCGAGCUUGAGAUGGACGCGCUCUCAACCCAGCGCUAAUU
AAAGAAACAACUGGCUCAAACGCCUUCGCGACACUCCAGAUGUAGCCUCCACGC
AUGCCAUGUGGAAAGUGGAUAGGCUACACUCAAGCUCACCCUCUGGUCGGCGC
CUCUGCUGUUUCGGUACAGCGGUCGUGCCUCACUGAAUUGAUAUCUGGGCCC
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(SEQ ID NO: 2)

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 AA

[0070] Oligonucleotides of the present teachings, which include but are not limited to oligonucleotides which can serve as probes and/or primers for detecting a murine astrovirus, include the following non-limiting examples:

- (SEQ ID NO: 5)
CUUUGGAGGGGAGGACCAAAGCUCUUAUGGGC;
- (SEQ ID NO: 6)
CCAAGAAAGAGGCACTAGTGGCACTC;
- (SEQ ID NO: 7)
GTTTTTTTTTTTTTTTTTTTTTTTGCCAATTTTTATGCCAATTATATACCC
C;
- (SEQ ID NO: 8)
TACATCGAGCGGGTGGTCGC;
- (SEQ ID NO: 9)
GTGTCTACTAACCGCGCACCTTTTCA;
and
- (SEQ ID NO: 10)
TTTGGCATGTGGTTAA.

[0071] In various aspects, an oligonucleotide can be RNA, DNA or a synthetic analogue such as a peptide nucleic acid. In various aspects, an oligonucleotide of the present teachings can further comprise one or more labels, such as a fluorophore, a fluorescence quencher, a hapten such as biotin, or a radioisotope such as ³³H, ¹⁴C, ³²P, ³³P, ³⁵S, or ¹²⁵I.

[0072] Oligopeptides of the present teachings, which include but are not limited to peptides that can serve as antigens for a vaccine, an antibody or a serum conversion assay, or a competitive probe for an antibody-based assay such as a radioimmunoassay include, without limitation,

- (SEQ ID NO: 11)
CGGDRNRWPYRNQIE
and
- (SEQ ID NO: 12)
CSEFLAQRESRGHAE.

EXAMPLES

[0073] The present teachings including descriptions provided in the Examples that are not intended to limit the scope of any claim or aspect. Unless specifically presented in the past tense, an example can be a prophetic or an actual example. The following non-limiting examples are provided to further illustrate the present teachings. Those of skill in the art, in light of the present disclosure, will appreciate that many changes can be made in the specific embodiments that are disclosed and still obtain a like or similar result without departing from the spirit and scope of the present teachings.

Example 1

[0074] This example demonstrates the detection of astroviruses using next generation sequencing.

[0075] In these experiments, to examine the mouse virome in an unbiased manner, fecal RNA and DNA libraries from three immunocompetent C57BL/6 (B6) mice were generated. The fecal RNA and DNA libraries were sequenced using 454 (pyrosequencing) technology (Roche) and VirusHunter was used to analyze the resulting reads. 100 mg of frozen stool was chipped and then resuspended in 6 volumes of PBS (Finkbeiner, S. R., et al., PLoS. Pathog. 4: e1000011, 2008). The sample was centrifuged to pellet particulate matter and the supernatant was then passed through a 0.45 μm filter. Total nucleic acid was isolated from 200 μL primary stool filtrate using AMPLIPREP DNA extraction machine (Roche) according to manufacturer's instructions. To enable subsequent detection of both RNA and DNA viruses, total nucleic acid from each sample was reverse transcribed and amplified as previously described (Wang, D., et al., PLoS Biol. 1: E2, 2003). Briefly, RNA templates were reverse transcribed using primerA containing a 16-nucleotide specific sequence followed by 9 random nucleotides for random priming. The 16-nucleotide specific sequence is unique for each sample and served as a barcode in assigning sequencing reads to a sample. SEQUENASE (United States Biochemical) was used for second strand cDNA synthesis and for random-primed amplification of DNA templates using PrimerA. Each sample was then subjected to 40 cycles of PCR amplification using PrimerB containing the same 16 nucleotide specific sequence as in the corresponding PrimerA. Amplification products

were pooled, adaptor-ligated and sequenced at the Washington University Genome Sequencing Center on the 454 GS-FLX platform (454 Life Sciences).

[0076] Sequences were analyzed using customized pipeline VirusHunter as described (Zhao, G., et al., *J. Virol.* 85: 10230-8, 2011). Briefly, sequence reads were assigned to samples based on the unique barcode sequences (i.e. PrimerB sequences). For further analysis, primer sequences were trimmed off and the sequence reads were clustered using CD-HIT (Li, W., and Godzik, A., *Bioinform.* 22: 1658-9, 2006) to identify redundant reads. Sequences were clustered on the basis of 95% identity over 95% sequence length, and the longest sequence from each cluster was picked as the representative sequence. Then, unique sequences were masked by REPEATMASKER (<http://www.repeatmasker.org>). If a sequence did not contain a stretch of at least 50 consecutive non-"N" nucleotides or if greater than 40% of the total length of the sequence is masked, it was removed from further analysis (i.e., "filtered"). Good quality sequences after filtering were sequentially compared against (i) the human genome using BLASTn; (ii) GenBank nt database using BLASTn; (iii) GenBank nr database using BLASTx (Altschul, S. F., et al., *J. Mol. Biol.* 215: 403-10, 1990); Minimal e-value cutoffs of $1e^{-10}$ and $1e^{-5}$ were applied for BLASTn and BLASTx, respectively. Sequences were phylotyped as human, mouse, fungal, bacterial, phage, viral, or other based on the identity of the top BLAST hit. Sequences without any significant hit to any of the databases were placed in the "unassigned" category. If a sequence aligns to both a virus and other kingdom (e.g. bacteria or fungi) with the same e value it is classified as "ambiguous". All eukaryotic viral sequences were further classified into viral families based on the taxonomy ID of the best hit.

[0077] All viral sequences and unassigned sequences from each sample were assembled into contigs using NEWBLER (454 Life Sciences) with default parameters. Sample 31H_B6_CR6 and 31H_B6_untreated were sequenced twice. Both sequencing data from each sample were used to try to obtain the best assembly.

[0078] 132 astrovirus sequences were identified: 21, 76, and 35 from mouse A, B, and C, respectively. No other viral reads were identified. The viral and unassigned reads detected in the feces of mouse B were used to assemble a 6,748-nucleotide (nt) contig with 9-fold coverage. A BLASTn (Altschul, S. F., et al., *J. Mol. Biol.* 215: 403-10, 1990) search of the NCBI nt database identified this contig to be a highly divergent astrovirus with at most 60% amino acid identity to Human Astrovirus 6 isolate Katano (FIG. 1). Reads detected in the feces of mouse C were used to assemble four contigs ranging from 288 to 3095 nt with 99.0-99.7% nt identity to the 6,748-nt contig from mouse B. Reads detected in the feces of mouse A were used to assemble three contigs ranging from 1024 to 2463 nt with 89.1-95.2% identity to mouse B contig00001 (FIG. 1). These data show the presence of at least two unidentified astroviruses in a specific-pathogen free research facility.

Example 2

[0079] This example illustrates the generation and sequencing of full-length murine astrovirus genomes.

[0080] In these experiments, subsequent analysis of the fecal specimens from mouse B and mouse C utilizing rapid amplification of cDNA ends (RACE) reactions and traditional Sanger sequencing generated the complete consensus

genomes of the two mouse astroviruses: MoAstV STL CY1 and MoAstV STL CY2 (FIG. 2).

[0081] Total RNA was extracted from the murine stool samples previously used in the deep sequencing reaction using an RNEASY mini kit (Qiagen, Valencia, Calif.). One microgram of RNA was used as the template for Rapid Amplification of cDNA Ends (RACE) reactions to generate the 5' and 3' genome ends using 5' RACE and 3' RACE kits (Invitrogen, Carlsbad, Calif.) according to the manufacturer's instructions. To generate full genomic sequences, one microgram of RNA was used as the template for cDNA synthesis using the SUPERScript III first-strand synthesis kit and an oligo(dT)₁₂₋₂₀ primer (Invitrogen) according to the manufacturer's instructions. Full genomic sequences were then amplified using ELONGASE Enzyme Mix (Invitrogen) and primers 5'-CCAAGAAAGAGGCACTAGTGGCACCTC-3' (SEQ ID NO:6) and 5'-GTITITITITITITITITITGCCAAT-TTTTATGCCAATTATATCACCC-3' (SEQ ID NO:7). The 6.7 kb PCR product was gel purified and ligated into a pCR4-TOPO TA sequencing vector (Invitrogen). Universal M13 forward and reverse primers were used for sequencing, and primer walking was applied as needed. Four clones with 2 to 4-fold redundancy each were used to construct consensus sequence 1 using GENEIOUS Pro v5.0 (Biomatters Ltd.) (Bosma, M. J., and Carroll, A. M., *Ann. Rev. Immun.* 9: 323-50 m 1991). Three clones with 2 to 4-fold redundancy each were used to construct consensus sequence 2. Predicted ORFs were identified using GENEIOUS. Protein motifs were predicted using Pfam (Finn, R. D., et al., *Nuc. Acid. Res.* 38: D211-D222, 2010).

[0082] Comparison of the MoAstV STL CY1 genome to contig BI generated by 454 pyrosequencing showed 99.9% nt identity, demonstrating that they are the same virus. Comparison of the MoAstV STL CY2 genome to contigs A00001, A00002, and A00010 generated by 454 pyrosequencing showed 99.6-99.9% nt identity, demonstrating that they are the same virus.

Example 3

[0083] This example illustrates that the MoAstV STL genome organization is consistent with other mamastroviruses.

[0084] In these experiments, the complete genome length of MoAstV STL CY1 and MoAstV STL CY2 was 6,817 nt, excluding the poly-A tail. MoAstV STL CY1 and MoAstV STL CY2 were predicted to contain a 5' untranslated region (UTR), three open reading frames (ORF 1a, 1b, and 2), a 3' UTR, and a polyA tail. The 5' and 3' UTR were determined to be 46 and 90 nt in length, respectively.

[0085] ORF1a of MoAstV STL CY1 and MoAstV STL CY2 was predicted to encode a 928 as protein containing a trypsin-like peptidase domain and showed significant similarity to known astroviruses by BLASTP (Altschul, S. F., et al., *J. Mol. Biol.* 215: 403-10, 1990). The 58-nt ORF1a/1b junction of MoAstV STL CY1 and MoAstV STL CY2 contained the heptanucleotide frameshift signal (AAAAAAC) conserved in all astroviruses (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Jiang, B., et al., *P. Natl. Acad. Sci. USA.* 90: 10539-43, 1993; Lewis, T. L. and Matsui, S. M., *Arch. Virol.* 140:1127-35, 1995; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). Furthermore FSFinder analysis (Moon, S., et al., *Nucleic. Acids. Res.* 32: 4884-92, 2004) confirmed that the downstream sequence was capable of generating a stem-loop structure required for a-1

ribosomal frameshift to lead to ORF1b translation (Brierley, I., et al., *Biochem. Soc. T.* 36: 684-9, 2008; Giedroc, D. P. and Comish, P. V., *Virus Res.* 139: 193-208, 2009; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007). The first amino acid in frame with the frameshift signal was predicted to be the start position for ORF1b of MoAstV STL CY1 and MoAstV STL CY2. ORF1b of MoAstV STL CY1 and MoAstV STL CY2 is predicted to encode a 502 aa protein containing an RNA dependent RNA polymerase (RdRP) domain, consistent with other astroviruses (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011; Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007).

[0086] MoAstV STL contained a sequence upstream of ORF2—highly conserved among mammalian astroviruses—CUUUGGAGGGAGGACCAAAGCUCUUAUGGGC (SEQ ID NO: 5), which encompasses the ORF2 start codon (in bold) and is suggested to be a promoter for sgRNA synthesis (Mendez, E. and Arias, C. F., *Fields Virology*, 5th ed. p. 981-99, 2007; Walter, J. E., et al., *Arch. Virol.* 146: 2357-67, 2001). As in most other mamastroviruses (De Benedictis, P., et al., *Infect. Genet. Evol.* 11: 1529-44, 2011), MoAstV STL had an 8-nt region of overlap at the end of ORF1b and beginning of ORF2, with ORF2 maintained in the same frame as ORF1a. ORF2 of MoAstV STL CY1 and MoAstV STL CY2 was predicted to encode an 819-aa protein containing the structural capsid protein.

[0087] Collectively, these data demonstrate that the genome organization of MoAstV STL CY1 and MoAstV STL CY2 is consistent with other members of the Astroviridae family, and the mamastrovirus genus in particular.

Example 4

[0088] This example illustrates that MoAstV STL viruses are members of a new mamastrovirus genogroup.

[0089] In these experiments, to evaluate the relationship between MoAstV STL CY1 and MoAstV STL CY2 and other known astroviruses, phylogenetic analysis was performed using aa sequences predicted to correspond to the capsid-containing ORF2. Analyses performed for ORF1a and 1b showed similar relationships. In all analyses, MoAstV STL clustered with the mamastrovirus genus and not the avastrovirus genus.

[0090] Sequences from astrovirus genomic segments encoding ORF1a, 1b, and 2 were translated. These sequences were aligned using ClustalX 2.0.12 (Larkin, M. A., et al., *Bioinform.* 23: 2947-8, 2007). Phylogenetic inference was performed with maximum parsimony using PAUP 4b10 and maximum likelihood using RAxML (Stamatakis, A., *Bioinform.* 22: 2688-90, 2006) and BLOSUM62 transition matrix methods with 1000 bootstrap replicates. The resulting phylogenetic trees were visualized using FIGTREE 1.3.1 (<http://tree.bio.ed.ac.uk/software/figtree>). MEGA 5.05 was used for distance estimation (uncorrected p-distance) (Tamura, K., et al., *Mol. Biol. Evol.* 28: 2731-9, 2011).

[0091] The MoAstV STL viruses were most closely related to a clade of recently characterized porcine and wild boar astroviruses, but shared only 33-36% amino acid identity in the capsid region and 63-67% amino acid identity in the RdRp region. This genetic grouping also included the recently deposited mouse astrovirus sequence derived from laboratory mice in Cincinnati, murine astrovirus strain TF18LM but was highly divergent from mouse astrovirus M-52/USA/2008, previously detected in wild mice (Phan, T. G., et al., *PLoS Pathog.* 7: e1002218, 2011).

[0092] In analyses of ORF2, the MoAstV STL viruses formed a distinct genetic cluster with a mean amino acid genetic distance (p-dist) of 0.762 ± 0.010 and 0.789 ± 0.010 to mamastrovirus genogroups I and II, respectively. Intra-group p-dists were 0.548 ± 0.010 , 0.629 ± 0.011 , and 0.641 ± 0.009 for mamastrovirus genogroups I, II, and the MoAstV STL genetic cluster, respectively.

[0093] Collectively, these data demonstrate that MoAstV STL is a mammalian astrovirus and is likely a member of a new third genogroup of mamastroviruses.

Example 5

[0094] This example illustrates that adaptive immunity is required to control MoAstV replication.

[0095] In these experiments, since MoAstV STL CY1 and MoAstV STL CY2 were originally identified in the feces of asymptomatic B6 mice, whether MoAstV STL was present in the feces of other mice from the same specific-pathogen free research mouse colony was examined. First, astrovirus was detected in immunocompromised mice in the cleanest barrier facility by PCR (FIG. 3). In FIG. 3, B-cell deficient mice are labeled MuMT and RAG deficient mice are labeled B6 RAG. To quantify the number of MoAstV STL CY1 and MoAstV STL CY2 genome copies in tissues and feces, a Taqman-based quantitative reverse transcriptase PCR (qRT-PCR) assay was designed (FIG. 4a), which targeted a 72-bp region of the RdRP conserved between MoAstV STL CY1 and MoAstV STL CY2.

[0096] Total RNA was extracted from individual stool pellets using an RNeasy mini kit (Qiagen) or from tissue samples using Trizol reagent (Invitrogen). One tenth of the total stool RNA or 1 μ g of tissue RNA was reverse transcribed using ImpromII RT (Promega, Madison, Wis.) and random primers (Invitrogen) to yield cDNA. Triplicate qPCR reactions were performed using one tenth of the cDNA, primers specific to an 80 nt region of ORF1b (sense: 5'-TACATCGAGCCGCKTG-GTCGC-3' (SEQ ID NO: 8); antisense: 5'-GTGTCAC-TAACGCGCACCTTITCA-3') (SEQ ID NO: 9), and a Taqman probe (Applied Biosystems, Foster City, Calif.) with the sequence 5'-TTGGCATGTGGGTAA-3' (SEQ ID NO:10) containing a 5' 6-carboxyfluorescein (6FAM) dye label, 3' nonfluorescence quencher (NFQ) and minor groove binder (MGB). The number of genome copies per sample was determined by comparison to a standard curve (generated by a 10-fold dilution of target-containing-plasmid in tRNA (Invitrogen)). For stool samples, the number of genome copies per sample was multiplied by 100 to account for dilution from total RNA originally extracted from the stool pellet and are reported as genome copies per stool pellet.

[0097] Across multiple experiments, the assay was able to repeatedly detect from 10^6 to 10^1 genome copies, and 1 genome copy was detected in 2 of 3 technical replicates consistent with Poisson distribution statistics, suggesting that this assay was both sensitive and robust.

[0098] Given that previous human studies have implicated the adaptive immune system as essential in the control of astrovirus pathogenesis (Wood, D. J., et al., *J. Med. Virol.* 24:435-44, 1988), the number of astrovirus genome copies were measured in the feces of mice deficient in B and T cells due to a mutation in Recombination Activating Gene 1 [RAG1, (Mombaerts, P., et al., *Cell.* 68: 869-77, 1992). While these mice exhibited no overt signs of illness, up to 10^9 astrovirus genome copies per fecal pellet were detected and notably, 21/21 RAG^{-/-} mice screened were positive for astro-

virus. These data suggest that adaptive immunity is essential for restricting MoAstV replication.

Example 6

[0099] This example illustrates that innate and adaptive immunity contributes to the control of MoAstV replication.

[0100] In these experiments, to assess the relative hierarchy of innate and adaptive immunity in restricting MoAstV replication, the timecourse of natural astrovirus infection in B6 and RAG1^{-/-} mice were examined, as well as mice deficient in STAT1^{-/-} (STAT1^{-/-}). C57BL/6J, B6.RAG1^{-/-}, and STAT1^{-/-} mice were bred and housed in an enhanced barrier specific-pathogen-free facility at Washington University in St. Louis in compliance with federal and institutional guidelines (Cadwell, K., et al., Cell. 141: 1135-45, 2010). All studies were performed using age-matched female mice between eight and ten weeks of age. Three mice, one of each genotype, were cohoused on day 0, and fecal samples were collected every 2 days to follow astrovirus shedding. Mice were euthanized on day 14 and tissues were harvested for analysis.

[0101] As previous studies have shown that astrovirus infections can spread beyond the gastrointestinal tract (Blomström, A. L., et al., J. Clin. Microbiol. 48: 4392-6, 2010; Quan, P. L., et al., Emerg. Infect. Dis. 16: 918-25, 2010), the distribution of MoAstV was investigated in multiple tissues as well as feces. In order to address the potential presence of additional astrovirus strains that might not be detectable by the TAQMAN assay, B6, STAT1^{-/-}, and RAG1^{-/-} mice were cohoused for 14 days to ensure infection by the same viruses occurred.

[0102] High levels of MoAstV shedding in fecal samples were observed in RAG1^{-/-} mice at day 0 and at all timepoints tested (FIG. 4b). In contrast, low levels of MoAstV were observed in the feces of both B6 and STAT1^{-/-} mice at day 0, prior to cohousing. Two days of cohousing, elevated levels of MoAstV genome copies were detected in feces from B6 and STAT1^{-/-} mice, with STAT1^{-/-} mice shedding significantly more MoAstV than B6 mice at day 2 (p<0.05). Overall, MoAstV shedding over the course of the experiment differed significantly by genotype (p<0.0001 for all combinations).

[0103] The tissue distribution of MoAstV STL was analyzed after 14 days of cohousing. High levels of genome copies in the GI tract of RAG1^{-/-} mice were detected (FIG. 4c), consistent with the observation that RAG1^{-/-} mice shed up to 10⁹ genome copies per stool pellet. The quantity of viral genome copies detected in the GI tract of B6 and STAT1^{-/-} mice were significantly lower than in the RAG1^{-/-} mice (p<0.001 for all GI tract tissues tested). While MoAstV RNA was detected in the liver and kidney of RAG1^{-/-} mice, it was not detected in the liver or kidney of B6 or STAT1^{-/-}. A limited number of genome copies in the spleen of STAT1^{-/-} mice were detected, twice as many as observed in the spleen of wild-type mice, though this comparison was not statistically significant. MoAstV STL was undetectable in the brain of any mouse tested, in contrast to previously identified enteric mouse pathogens in immunocompromised mice (Karst, S. M., et al., Science. 299: 1575-8, 2003).

[0104] These data demonstrate a role for both the innate and adaptive immune systems in the control of astrovirus infection and replication.

Example 7

[0105] This example illustrates that MoAstV is present in mice from commercial mouse colonies.

[0106] In these experiments, the presence of MoAstV in mice available from commercial vendors was assessed. Since extremely high levels of MoAstV STL in the feces of RAG1^{-/-} mice were previously observed, the present inventors decided to assess the presence of MoAstV STL in commercially available mice lacking B and T cells. RAG1^{-/-} mice (B6.129S7-Rag1^{tm1.1Mom1/J}, cat #002216) were purchased from The Jackson Laboratory, RAG2^{-/-} mice (129S6/SvEvTac-Rag2^{tm1.Fwa}, cat#RAG2-F) (Shinkai, Y., et al., Cell. 68: 855-67, 1992) from Taconic facility IBU25, and SCID mice (CB17/Icr-Prkdc^{scid}/IcrCrl, cat#236) (Bosma, M. J., and Carroll, A. M., Ann. Rev. Immun. 9: 323-50 m 1991) from Charles River facility WO9—the three major mouse vendors in the United States. Mice were sacrificed immediately upon arrival and samples were collected for analysis.

[0107] Consistent with previous findings (FIG. 4), extremely high levels of MoAstV STL were observed in fecal and tissue samples from RAG1^{-/-} and RAG2^{-/-} mice (FIG. 5). MoAstV was undetectable in the feces or tissues of SCID mice. Overall, however, these data suggest that MoAstV STL is a common pathogen, likely present in many research mouse facilities in the United States.

Example 8

[0108] This example illustrates antibody responses during murine astrovirus infection.

[0109] In these experiments, B6 mice were inoculated with MuAstV or mock-inoculated. Serum antibody responses measured at 16 days. Differences in MuAstV-specific antibodies were observed between MuAstV- and mock-inoculated mice (p<0.02; Mann-Whitney test) (FIG. 6).

[0110] The astrovirus capsid protein can assemble into virus-like particles (VLP) which share biological properties of virions. A baculovirus system was used to express the capsid protein of MuAstV strain STL 2. The ability of MuAstV VLP to detect serum antibodies specific to MuAstV by ELISA were validated using MuAstV VLP compared to MNV virions, as well as MuAstV and MNV-inoculated mice (data not shown). Using this assay, an elevation of virus-specific antibodies was observed in the serum of MuAstV-inoculated mice compared to mock-inoculated control mice (FIG. 6). These data demonstrate that VLP derived from the sequence of the capsid protein of MuAstV STL2 can detect a serological response to MuAstV infection, which can be used for the establishment of MuAstV-free mice.

Example 9

[0111] This example illustrates the prevalence of murine astrovirus in a specific pathogen-free breeding facility.

[0112] Fecal pellets were obtained from mice from Dec. 4, 2011-Jan. 15, 2012 and the presence of murine astrovirus tested by quantitative RT-PCR. Limit of detection=100 genome copies/fecal pellet. Mice were housed 1-5 mice/cage, on 7 racks in 1 breeding room. Bedding sentinels were housed 2 mice/cage, 1 cage/rack in the same room.

[0113] MuAstV sequences were detected by next generation sequencing or quantitative PCR (qPCR) in the feces of mice from at least six research institutions and two commercial vendors. Furthermore, MuAstV was detected by qPCR in 73% of mouse lines in a single breeding room at Washington

University School of Medicine (Table. 1). These results demonstrate that the prevalence of MuAstV in laboratory mice can be equal to or greater than that of murine norovirus (MNV), which is the most prevalent, recognized viral agent in laboratory mice today.

TABLE 1

	Mice				Sentinels	
	# of mice	# of cages	# of lines	# of racks	# of mice	# of cages
MuAstV positive	122	72	32	7	5	3
Total tested	485	178	44	7	14	7
Prevalence of MuAstV	25%	40%	73%	100%	36%	43%

Example 10

[0114] This example illustrates genetic diversity of murine astroviruses identified by next-generation sequencing.

[0115] Virus contigs from fecal samples (red) were aligned with known (black) MuAstV sequences using ClustalW. A maximum-likelihood phylogenetic tree was generated using MEGA.

[0116] Shotgun sequencing of libraries of RNA and DNA isolated from 35 fecal samples from laboratory rodents using the 454 GS FLX Titanium platform generated an average of 31,781 high quality reads per sample. The virome was examined using VirusHunter. Sequences with 76-99% nucleotide (nt) identity to MuAstV strain STL 1 were detected in mouse samples (example sequences illustrated in FIG. 7). These data demonstrate that MuAstV can be genetically diverse.

Example 11

[0117] This example illustrates kinetics of murine astrovirus shedding.

[0118] In these experiments, C57BL/6 (B6) and STAT1^{-/-} mice were inoculated with MuAstV and shedding in feces was measured. RAG1^{-/-} mice were naturally infected with MuAstV and shedding in feces measured for 14 days. Differences in MuAstV shedding were observed between B6 and STAT1^{-/-} mice at 6-12 days (p<0.05; one way ANOVA); significant differences in MuAstV shedding were observed between B6 and RAG1^{-/-} mice, STAT1^{-/-} and RAG1^{-/-} mice at all time points (p<0.05; one way ANOVA).

[0119] Experiments using naturally-infected RAG1^{-/-} mice co-housed with B6 and STAT1^{-/-} mice suggest that both innate and adaptive immunity control MuAstV replication. Since the high level, sustained shedding observed in RAG1^{-/-} mice may confound the kinetics of MuAstV replication and clearance in co-housed B6 and STAT1^{-/-} mice, MuAstV

shedding in B6 and STAT1^{-/-} mice orally inoculated with a filtered fecal stock of MuAstV containing 5×10⁵ genome copies of MuAstV was re-examined (FIG. 8). Peak MuAstV shedding was reached 6 days after inoculation in B6 and STAT1^{-/-} mice. MuAstV shedding was elevated in STAT1^{-/-} mice compared to B6 mice confirming a role for innate immunity in control of MuAstV replication (FIG. 8). MuAstV shedding declined to baseline in B6 and STAT1^{-/-} mice 16 days after inoculation (FIG. 8), demonstrating that innate immunity can not necessarily be required to control MuAstV clearance.

Example 12

[0120] This example illustrates specificity of an ELISA for Astrovirus (AstV) virus-like particles (VLP), and that an ELISA can be used to detect AstV-specific antibodies in mice previously infected with AstV.

[0121] Astrovirus VLP generation—The astrovirus capsid protein can assemble into virus-like particles (VLP) which share the biological properties of virions (Moser, L., et. al., J. Virol. 81:11937-45, 2007). To generate virus-like particles, cDNA corresponding to ORF2 of STL CY2 was tagged with a 3' TEV recognition site and 6×His tag and cloned into a pFastBac1 donor vector (Invitrogen) for baculovirus expression. Protein was generated and astrovirus VLPs were purified.

[0122] Astrovirus ELISA validation—ELISA plates were coated with serial dilutions of astrovirus VLPs and blocked with 3% BSA prior to use. Serum samples from mock and infected mice were added to the ELISA plate at a 1:100 dilution. Astrovirus VLP-specific antibodies were detected by goat-anti-mouse HRP antibodies (Jackson Immunoresearch) and ABTS peroxidase substrate (ThermoScientific) Signal was detected using a BioRad IMARK microplate reader at 415 nm. Based on the interpolated standard curve (FIG. 9), a concentration of 0.1 ng/L astrovirus VLPs was selected for use in future experiments.

[0123] To further test for specificity, ELISA plates were coated with astrovirus VLPs or UV-inactivated murine norovirus MNV virions. Serum samples from mock, AstV-infected, and MNV-infected mice were analyzed. The data (FIG. 10) validate specificity of the test.

[0124] Astrovirus ELISA screen—C57BL/6J mice were orally inoculated on days 0 and/or 18 with 5e5 genome copies of a heterogeneous AstV solution or PBS (mock infected). At day 34 post infection, serum was collected for analysis by ELISA. (FIG. 11). The data illustrate detection of murine astrovirus antibodies by ELISA.

[0125] All references cited herein are incorporated by reference, each in its entirety. Applicant reserves the right to challenge any conclusions presented by the authors of any reference.

SEQUENCE LISTING

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<212> TYPE: RNA

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<210> SEQ ID NO 3

<211> LENGTH: 2610

<212> TYPE: RNA

<213> ORGANISM: Mouse Astrovirus

<400> SEQUENCE: 3

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ccagaaugcg cccuacaccg gccacucuu ucuugccgag gucacaggca ccuggagguu 780
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<210> SEQ ID NO 4

<211> LENGTH: 2616

<212> TYPE: RNA

<213> ORGANISM: Mouse Astrovirus

<400> SEQUENCE: 4

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gcagacuccu cgcgagguug uccagacggg uacggcgacc cucggaacgg uggcgcgaa 300
ccagggcgau caggucgagc uugagauggc agcgcuccuc agcccagcgc ugaucaagga 360
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<210> SEQ ID NO 5
<211> LENGTH: 34
<212> TYPE: RNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

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<400> SEQUENCE: 5

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<210> SEQ ID NO 6
<211> LENGTH: 26
<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

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<400> SEQUENCE: 6

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ccaagaaaga ggcactagt gcaactc 26

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<210> SEQ ID NO 7
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<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

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<400> SEQUENCE: 7

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<210> SEQ ID NO 8
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<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

<400> SEQUENCE: 8

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<210> SEQ ID NO 9
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<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

<400> SEQUENCE: 9

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<210> SEQ ID NO 10
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<212> TYPE: DNA
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial Oligonucleotide

<400> SEQUENCE: 10

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<210> SEQ ID NO 11
<211> LENGTH: 15
<212> TYPE: PRT
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial OligoPeptide

<400> SEQUENCE: 11

Cys Gly Gly Asp Arg Asn Arg Trp Pro Tyr Arg Asn Gln Ile Glu
1           5           10           15

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<210> SEQ ID NO 12
<211> LENGTH: 15
<212> TYPE: PRT
<213> ORGANISM: Artificial Sequence
<220> FEATURE:
<223> OTHER INFORMATION: Artificial OligoPeptide

<400> SEQUENCE: 12

Cys Ser Glu Phe Leu Ala Gln Arg Glu Ser Arg Gly His Ala Glu
1           5           10           15

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What is claimed is:

1. An oligonucleotide consisting of a sequence of from 10 to 70, or about 70 nucleotides, wherein said oligonucleotide hybridizes to a nucleic acid of a murine astrovirus or the complement thereof under high stringency conditions.

2. An oligonucleotide in accordance with claim 1, wherein the oligonucleotide comprises, consists essentially of, or consists of a sequence consisting of from 10 to 60, or about 60 nucleotides.

3. An oligonucleotide in accordance with claim 1, wherein the oligonucleotide consists of a sequence of from 10 to 50, or about 50 nucleotides.

4. An oligonucleotide in accordance with claim 1, wherein the oligonucleotide consists of a sequence of from 10 to 30, or about 30 nucleotides.

5. An oligonucleotide in accordance with claim 1, wherein the oligonucleotide consists of a sequence selected from the group consisting of

(SEQ ID NO: 5)
CUUUGGAGGGGAGGACCAAAGCUCUUCUUGGGC,

(SEQ ID NO: 6)
CCAAGAAAGAGGCACTAGTGCACTC,

-continued

(SEQ ID NO: 7)
 GTTTTTTTTTTTTTTTTTTTTGGCCAATTTTATGCCAATTATATACCC

c,

(SEQ ID NO: 8)
 TACATCGAGCGGGTGGTCGC,

(SEQ ID NO: 9)
 GTGTCACTAACGCGCACCTTTTCA
 and

(SEQ ID NO: 10)
 TTTGGCATGTGGGTAA.

6. A method of detecting presence, absence or quantity of a murine astrovirus in a biological sample, the method comprising:

providing a sample comprising or suspected of comprising an astrovirus;

contacting the sample with at least one nucleic acid probe comprising a sequence of at least 10 nucleotides wherein the nucleic acid probe is complementary to a nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence or the complement thereof, under hybridization conditions; and

detecting presence, absence or quantity of a hybrid nucleic acid comprising the probe and the astrovirus nucleic acid.

7. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 6, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 80% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

8. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 6, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 90% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

9. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 6, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has at least 95% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

10. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 6, wherein the nucleotide sequence that has at least 70% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof, has 100% sequence identity with an astrovirus nucleic acid sequence, or the complement thereof.

11. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 6, wherein the detecting comprises a quantitative PCR assay.

12. A method of detecting presence, absence or quantity of an astrovirus in a biological sample in accordance with claim 11, wherein the quantitative PCR assay is a quantitative RT-PCR assay.

13. A method according to claim 6, wherein the sample is selected from the group consisting of a fecal sample, a vomitus sample, a tissue sample and a blood sample.

14. An oligopeptide consisting of at least 9 amino acid residues up to 60 amino acid residues, or about 60 amino acid residues of a murine astrovirus antigen.

15. An oligopeptide in accordance with claim 14, wherein the oligopeptide consists of at least 10 up to about 50 amino acid residues.

16. An oligopeptide in accordance with claim 14, wherein the oligopeptide consists of at least 12 up to about 40 amino acid residues.

17. An oligopeptide in accordance with claim 14, wherein the oligopeptide consists of at least 15 up to about 30 amino acid residues.

18. An oligopeptide in accordance with claim 14, wherein the oligopeptide consists of about 15 amino acid residues.

19. An oligopeptide in accordance with claim 14, wherein the oligopeptide has a sequence selected from the group consisting of CGGDRNRWPYRNQIE (SEQ ID NO: 11) and CSEFLAQRESRGHAE (SEQ ID NO:12).

20. An antibody directed against an oligopeptide of claim 14.

* * * * *