

1 Full title

2 Basic reproduction numbers of three strains of mouse hepatitis viruses in mice

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4 Short title

5 DYNAMICS OF MHV IN MICE

6

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15

## 16     **Abstract**

17     Mouse hepatitis virus (MHV) is a murine coronavirus and one of the most important  
18     pathogens in laboratory mice. Although various strains of MHV have been isolated, they  
19     are generally excreted in the feces and transmitted oronasally via aerosols and  
20     contaminated bedding. In this study, we attempted to determine the basic reproduction  
21     numbers of three strains of MHV to improve our understanding of MHV infections in  
22     mice. Five-week-old female C57BL/6J mice were inoculated intranasally with either the  
23     Y, NuU, or JHM variant strain of MHV and housed with two naive mice. After 4 weeks,  
24     the presence or absence of anti-MHV antibody in the mice was determined by the  
25     enzyme-linked immunosorbent assay. We also examined the distribution of MHV in the  
26     organs of Y, NuU, or JHM variant-infected mice. Our data suggest that the  
27     transmissibility of MHV is correlated with viral growth in the gastrointestinal tract of  
28     infected mice. To the best of our knowledge, this is the first report to address the basic  
29     reproduction numbers among pathogens in laboratory animals.

30

## 31 **Introduction**

32 The microbiological control of laboratory animals is essential to obtain reproducible and  
 33 stable experimental results, and mouse hepatitis virus (MHV) is a representative  
 34 pathogen for microbiological monitoring.<sup>1</sup> MHV is a single-stranded plus-sense RNA  
 35 virus with petal-like projections that belongs to the family *Coronaviridae*, and its  
 36 natural host is mice.<sup>2</sup> MHV causes hepatitis, enteritis, and encephalitis in mice, and its  
 37 pathogenesis varies depending on the viral strain, infectious dose, route of infection, and  
 38 the genetic background, age, and immune status of the host.<sup>3-5</sup> Experimental infection  
 39 with MHV has been used to generate hepatitis<sup>6,7</sup> and a demyelinating disease mouse  
 40 model.<sup>8-11</sup> Studies have also been conducted to elucidate the replication and  
 41 multiplication mechanisms of coronaviruses using MHV as a model.<sup>12,13</sup> In recent years,  
 42 the worldwide coronavirus disease 2019 pandemic caused by severe acute respiratory  
 43 syndrome coronavirus 2 (SARS-CoV-2) has led to the use of MHV as a surrogate for  
 44 SARS-CoV-2 in research on disinfectants.<sup>14,15</sup>

45 In Europe and the United States, MHV has the second highest infection rate in  
 46 laboratory animals after mouse norovirus and mouse parvovirus.<sup>16</sup> The spread of MHV  
 47 in animal research facilities causes wasting disease and death in immunocompromised  
 48 mice such as nude mice and suckling mice,<sup>17,18</sup> and subclinical infection in adult mice

49 reportedly modifies experimental performance in many experimental models.<sup>19</sup> MHV is  
 50 generally excreted in the feces of infected mice and is transmitted oronasally, but it is  
 51 also transmitted via aerosols and contaminated bedding.<sup>20</sup> Depending on the mouse  
 52 strain and immune status, MHV-infected mice excrete infectious MHV for several days  
 53 to several weeks.<sup>21</sup> Contamination by MHV in a specific pathogen-free laboratory  
 54 animal facility requires total culling of the infected mouse colony and disinfection of the  
 55 facility, and the impact is not small.<sup>22</sup> The basic principle of MHV infection control in  
 56 facilities housing laboratory animals is to prevent exposure of the animals to MHV.  
 57 Adequate quarantine is necessary when introducing new animals from other facilities. In  
 58 addition, wild mice infected with MHV,<sup>23</sup> pet mice,<sup>24,25</sup> and biological materials  
 59 obtained from infected mice are also sources of infection and should be handled with  
 60 care.<sup>26,27</sup> It is possible that the virus may be introduced into the facility unknowingly by  
 61 scientists or caretakers who come into contact with MHV-contaminated animals or  
 62 breeding equipment.

63 Serological methods such as the enzyme-linked immunosorbent assay (ELISA) and  
 64 indirect fluorescent antibody methods are commonly used to diagnose MHV in animal  
 65 testing facilities, and RT-PCR<sup>28</sup> and RT-nested PCR methods have also been used in  
 66 recent years.<sup>29,30</sup>

67 Pathogenicity and organ affinity vary among the many strains of MHV.<sup>2,31</sup> In  
 68 this study, we used the Y, NuU, and JHM variant strains. The Y strain was isolated from  
 69 suckling mice with symptoms of acute cecal colitis;<sup>32</sup> the NuU strain is a less  
 70 pathogenic strain that was isolated from nude mice with wasting disease;<sup>33</sup> and the JHM  
 71 strain was isolated from suckling mice with diarrhea.<sup>34</sup> The JHM strain is used to  
 72 produce a model of multiple sclerosis because it causes demyelinating encephalitis  
 73 when inoculated into the brain of mice.<sup>35</sup> However, the JHM strain induces acute fatal  
 74 encephalitis after intracerebral infection.<sup>3,36</sup> Therefore, we used the JHM variant 2.2-V-1  
 75 in this study, which was selected with monoclonal antibody J.2.2, and it loses the ability  
 76 to cause acute encephalitic illness after intracerebral inoculation.<sup>36</sup> When MHV is  
 77 inoculated intranasally into mice, it is believed to multiply in nasal epithelial cells and  
 78 spreads to other organs via the olfactory nerve, lymphatic system, and viremia.<sup>37</sup>

79 Although there have been reports comparing pathogenicity, physicochemical  
 80 properties,<sup>38</sup> and gene sequences of MHV viral strains,<sup>39,40</sup> no direct comparison of  
 81 transmissibility has been conducted. To gain a better understanding of MHV  
 82 epidemiology, we attempted to determine the basic reproduction numbers of three  
 83 strains of MHV in mice. The basic reproduction number ( $R_0$ ) is defined as the average  
 84 number of secondary infections generated by one infected individual in a population in

85 which all individuals are susceptible.<sup>41,42</sup> We also examined viral distribution in mice  
86 infected with each MHV for a better understanding of the dynamics of MHV infection  
87 in mice. The results of this study suggest that viral growth in the gastrointestinal tract  
88 plays an important role in the transmissibility of MHV.

89

## 90 **Materials and Methods**

### 91 **Mice**

92 Five-week-old, MHV-free, female C57BL/6J (B6) mice were purchased from Japan  
93 SLC (Shizuoka, Japan). Some mice were inoculated intranasally with MHV and kept in  
94 cages in a negatively pressured isolator (KIS-145; Ishihara Corporation, Osaka, Japan)  
95 in the animal room, which was maintained at a temperature of  $23 \pm 5^{\circ}\text{C}$ , humidity of  $55$   
96  $\pm 5\%$ , and 12-h illumination (light period: 8:00–20:00; dark period: 20:00–8:00). A  
97 plastic mouse breeding cage ( $220 \times 160 \times 125$  mm; Ishihara Corporation) with a  
98 stainless-steel wire top was used. Each cage was filled with approximately 1,000 mL  
99 bedding (ALPHA-dri; Shepherd Specialty Papers, Watertown, TN, USA). To avoid  
100 artificial transmission of MHV, the bedding was not changed during the experiment.  
101 Mice were fed  $\gamma$ -ray-sterilized pellets (CRF-1; Oriental Yeast Co., Ltd., Tokyo, Japan)  
102 and tap water *ad libitum* from a plastic bottle. The animal protocol was reviewed and  
103 approved by the Institutional Animal Committee for Use and Care at the Graduate

104 School of Agricultural and Life Sciences (University of Tokyo, Tokyo, Japan), and was  
105 conducted in accordance with the Animal Experiment Implementation Regulations and  
106 Animal Experiment Implementation Manual of the University of Tokyo.

107

## 108 **Viruses and cells**

109 Y,<sup>32</sup> NuU,<sup>33</sup> and JHM variant (2.2-V-1)<sup>36</sup> strains were cultured with DBT cells, which  
110 are MHV-sensitive.<sup>43</sup> The JHM variant 2.2-V-1 was a kind gift from Dr. John O Fleming  
111 (University of Southern California School of Medicine, Los Angeles, CA then). DBT  
112 cells were cultured in Eagle's minimal essential medium (E-MEM) containing 5% fetal  
113 bovine serum and 1% tryptose phosphate broth (Sigma-Aldrich Co., St. Louis, MO,  
114 USA) at 37°C in 5% CO<sub>2</sub> in humidified air.

115

## 116 **Viral infection experiments**

117 To determine the basic reproduction numbers of three stains of MHV in mice, the  
118 concentration of the Y, NuU, and JHM variant strains was adjusted to  $1 \times 10^4$  PFU/0.02  
119 mL saline solution and inoculated intranasally using a micropipette into 5-week-old  
120 female B6 mice under isoflurane inhalation anesthesia. Each inoculated mouse was  
121 maintained for 2 days in a cage. Then, one inoculated mouse was bred with two naïve

122 5-week-old, female B6 mice for 4 weeks. Four cages were prepared for the Y strain, and  
 123 five cages were prepared for the NuU and JHM variant strains. Subsequently, all mice  
 124 were euthanized. Serum was collected and frozen at  $-80^{\circ}\text{C}$  until use. To determine viral  
 125 growth in each organ in mice, B6 mice were inoculated intranasally with  $1 \times 10^4$   
 126 PFU/0.02 mL of each of the Y, NuU and JHM variant strains. Four mice each were  
 127 euthanized and necropsied on days 1, 3, and 5 after inoculation, and the brain, liver,  
 128 jejunum, ileum, and colon were aseptically sampled and frozen at  $-80^{\circ}\text{C}$  until use.

129

### 130 **Serological tests**

131 The anti-MHV antibody titer in mouse serum was determined by ELISA using a  
 132 commercially available ELISA kit (MONILISA® MHV 96-well; Wakamoto  
 133 Pharmaceutical Co., Ltd., Tokyo, Japan), and absorbance was measured using a plate  
 134 reader. Transmission from MHV-inoculated mice to naïve mice was judged by  
 135 seroconversion against MHV in naïve mice housed together with virus-inoculated mice.

136

### 137 **Quantification of infectious virus**

138 Quantification of infectious virus in organs was performed by the plaque assay.<sup>44</sup> Briefly,  
 139 tissue samples from the brain, liver, jejunum, ileus, and colon were homogenized in



140 chilled E-MEM to generate a 10% solution and then centrifuged at 3,000 rpm for 10  
141 min. Ten-fold serial dilutions were prepared, and each dilution was assayed for  
142 infectious viruses in duplicate in DBT cells. For samples from the jejunum, ileus, and  
143 colon, 5 mg/mL gentamicin sulfate (Wako Pure Chemical Industries, Ltd., Tokyo,  
144 Japan) was added to E-MEM when generating the suspensions.

145

#### 146 **Calculation of basic reproduction numbers**

147 In the mouse cohabitation experiment, the average number of antibody-positive mice  
148 derived from one infected mouse was calculated to be the basic reproduction number.

149

#### 150 **Statistical analyses**

151 The data obtained in the experiments were subjected to statistical analyses by the  
152 Wilcoxon rank-sum test, with  $P < 0.05$  considered statistically significant.

153

### 154 **Results**

#### 155 **Basic reproduction number of three MHV strains**

156 To determine the basic reproduction numbers of three strains of MHV, naïve mice were  
157 cohabitated with mice inoculated with either the Y, NuU, or JHM variant strain for 4

158 weeks, and anti-MHV antibody production was examined by ELISA. In all four cages  
159 administered the Y strain, all naïve mice cohabitating with the mouse inoculated with  
160 the Y strain were seroconverted (Fig. 1). For the NuU strain, one naïve mouse out of  
161 two in two cages produced anti-MHV antibodies. All naïve mice in the remaining three  
162 cages were negative. Among the five cages administered the JHM variant strain, three  
163 inoculated mice showed a positive antibody response while the remaining two did not.  
164 Neither naïve mouse cohabitating with JHM variant-infected mice were seroconverted.  
165 The basic reproduction number was calculated after excluding the cages in which the  
166 inoculated mice did not show a positive antibody response. As shown in Table 1, the  
167 basic reproduction numbers of the Y, NuU, and JHM variant strains were determined to  
168 be  $\geq 2$ , 0.4, and 0, respectively.

169

# **170 Viral growth in organs in Y, NuU, or JHM variant-infected mice**

171 To investigate the relationship between the basic reproduction number and viral growth  
172 in various organs in mice, viral growth in the brain, liver, jejunum, ileus, and colon was  
173 examined. Five-week-old, MHV-free female B6 mice ( $n = 4$  or  $5$ ) were inoculated with  
174  $1 \times 10^4$  PFU of the Y, NuU, or JHM variant strains, and the brain, liver, jejunum, ileus  
175 and colon were removed on days 1, 3, and 5 after inoculation. In mice inoculated with

176 the Y and NuU strains, infectious virus was detected in all organs examined (Table 2,  
177 Fig. 2). On the other hand, in mice inoculated with the JHM variant strain, infectious  
178 viruses in the jejunum, ileus, and colon were all below the detection limit. The amount  
179 of infectious virus detected in the brains of mice inoculated with the Y, NuU, and JHM  
180 variant strains tended to increase with each day of inoculation during the experiment  
181 (Fig. 2). On the other hand, there was no change in the mean amount of infectious virus  
182 detected in the liver of mice on days 3 and 5 after inoculation with the Y, NuU, and  
183 JHM variant strains. In mice inoculated with the Y and NuU strains, infectious virus  
184 was detected in the jejunum and ileus from day 1 after inoculation. In mice inoculated  
185 with the Y and NuU strains, the detection rate of infectious virus up to 3 days after  
186 inoculation was higher in the jejunum than in the ileus (Table 2). In mice inoculated  
187 with the Y and NuU strains, the detection rate of infectious virus in the colon by day 5  
188 after inoculation was less than 50%, which was the lowest among the organs examined  
189 (Table 2).

190

## 191 **Discussion**

192 Basic reproduction number is an important epidemiological parameter defined  
193 as the average number of secondary infections generated by one infected individual in a

194 population in which all individuals are susceptible.<sup>41,42</sup> Basic reproduction number is  
 195 not simple and is affected by numerous biological, sociobehavioral, and environmental  
 196 factors that govern pathogen transmission.<sup>45</sup> In this study, we attempted to determine the  
 197 basic reproduction number of MHV in mice in laboratory animal facilities. The data  
 198 suggest that the Y strain is the most transmissible, and the JHM variant is not  
 199 transmissible by cohabitation. There have been some reports addressing how MHV  
 200 spreads among mice in laboratory animal facilities,<sup>46,47</sup> but to the best of our knowledge,  
 201 no study has examined the basic reproduction number of MHV in mice.

202         Infectious virus was detected in all organs of mice inoculated with Y and NuU  
 203 strains, while infectious virus in the jejunum, ileus, and colon of mice inoculated with  
 204 JHM variant was below the detection limit. The difference in transmissibility between  
 205 the Y and JHM variants may be because the JHM variant is less likely to increase in the  
 206 gastrointestinal tract and be excreted in the feces compared with the Y strain in the case  
 207 of intranasal inoculation. The quantitative results of infectious virus in organs did not  
 208 explain the difference in transmissibility between the Y and NuU strains. For both  
 209 strains, examination of the amount of virus excreted in feces and excretion period using  
 210 another assay, for example, quantitative PCR is expected to provide evidence of a  
 211 difference in transmissibility. In addition, considering the infection route of MHV, we

212 could not exclude the possibility of physicochemical stability of each viral strain in the  
213 external environment where mouse feces are discharged.

214 Barthold *et al.*<sup>48</sup> detected infectious virus in the gastrointestinal tract at 3 and 5  
215 days after intranasal inoculation of BALB/cByJ mice with  $10^3$  of the median tissue  
216 culture infectious dose of the JHM strain. However, in this study, no infectious virus  
217 was detected in the gastrointestinal tract of C57BL/6J mice intranasally inoculated with  
218 the JHM strain. There are many substrains of JHM with different antigenicities.<sup>49</sup> The  
219 JHM strain used in this study is a variant strain resistant to S protein-specific  
220 monoclonal antibody<sup>36</sup> and is not identical to the strain used by Barthold *et al.*<sup>48</sup> The  
221 reason for the different results from those of Barthold *et al.* may be due to the difference  
222 in viral strain and host (BALB/cByJ vs. B6).

223 The cage and rack system have been developed and marketed for the purpose  
224 of better microbiological control of laboratory animals. MHV is a representative  
225 pathogen for mice and is used for the evaluation of system functions.<sup>50,51</sup> Based on our  
226 results, it may be possible to evaluate the protective function of cages and racks against  
227 MHV infection in mice by using a strain with relatively high transmissibility, such as  
228 the Y strain.

229

230     **Acknowledgements**

231     We thank Dr. John O. Fleming for providing a JHM variant (2.2-V-1).

232

233     **Declaration of Conflicting Interests**

234     The author(s) declare no potential conflicts of interest with respect to the research,

235     authorship, and/or publication of this article.

236

## 237     **References**

- 238     1. FELASA working group on revision of guidelines for health monitoring of rodents  
239         and rabbits, Mähler Convenor M, Berard M, Feinstein R, et al. FELASA  
240         recommendations for the health monitoring of mouse, rat, hamster, guinea pig and  
241         rabbit colonies in breeding and experimental units. *Lab Anim* 2014; 48:178-192.
- 242     2. Weiss SR and Leibowitz JL. Coronavirus pathogenesis. *Adv Virus Res* 2011;  
243         81:85-164.
- 244     3. Hirano N, Murakami T, Taguchi F, et al. Comparison of mouse hepatitis virus  
245         strains for pathogenicity in weanling mice infected by various routes. *Arch Virol*  
246         1981; 70:69-73.
- 247     4. Barthold SW. Host age and genotypic effects on enterotropic mouse hepatitis virus  
248         infection. *Lab Anim Sci* 1987; 37:36-40.
- 249     5. Kyuwa S, Tagawa Y, Shibata S, et al. Murine coronavirus-induced subacute fatal  
250         peritonitis in C57BL/6 mice deficient in gamma interferon. *J Virol* 1998;  
251         72:9286-9290.
- 252     6. Arévalo AP, Pagotto R, Pórfido JL, et al. Ivermectin reduces *in vivo* coronavirus  
253         infection in a mouse experimental model. *Sci Rep* 2021; 11:7132.
- 254     7. Grabherr S, Ludewig B and Pikor NB. Insights into coronavirus immunity taught

- 255 by the murine coronavirus. *Eur J Immunol* 2021; 51:1062-1070.
- 256 8. Savarin C and Bergmann CC. Fine Tuning the Cytokine Storm by IFN and IL-10
- 257 Following Neurotropic Coronavirus Encephalomyelitis. *Front Immunol* 2018;
- 258 9:3022.
- 259 9. Sariol A, Mackin S, Allred MG, et al. Microglia depletion exacerbates
- 260 demyelination and impairs remyelination in a neurotropic coronavirus infection.
- 261 *Proc Natl Acad Sci USA* 2020; 117:24464-24474.
- 262 10. Pan R, Zhang Q, Anthony SM, et al. Oligodendrocytes that survive acute
- 263 coronavirus infection induce prolonged inflammatory responses in the CNS. *Proc*
- 264 *Natl Acad Sci USA* 2020; 117:15902-15910.
- 265 11. Chakravarty D, Saadi F, Kundu S, et al. CD4 deficiency causes poliomyelitis and
- 266 axonal blebbing in murine coronavirus-induced neuroinflammation. *J Virol* 2020;
- 267 94:e00548-20.
- 268 12. Gribble J, Stevens LJ, Agostini ML, et al. The coronavirus proofreading
- 269 exoribonuclease mediates extensive viral recombination. *PLoS Pathog* 2021;
- 270 17:e1009226.
- 271 13. Cong Y, Ulasli M, Schepers H, et al. Nucleocapsid protein recruitment to
- 272 replication-transcription complexes plays a crucial role in coronaviral life cycle. *J*



- 273        *Viol* 2020; 94:e01925-19.
- 274    14. Ma B, Gundy PM, Gerba CP, et al. UV Inactivation of SARS-CoV-2 across the  
275        UVC spectrum: KrCl\* excimer, mercury-vapor, and LED sources. *Appl Environ*  
276        *Microbiol* 2021 :AEM0153221.
- 277    15. Pereira Oliveira G and Kroon EG. Mouse hepatitis virus: A betacoronavirus model  
278        to study the virucidal activity of air disinfection equipment on surface  
279        contamination. *J Virol Methods* 2021; 297:114274.
- 280    16. Pritchett-Corning KR, Cosentino J and Clifford CB. Contemporary prevalence of  
281        infectious agents in laboratory mice and rats. *Lab Anim* 2009; 43:165-173.
- 282    17. Ishida T and Fujiwara K. Pathology of diarrhea due to mouse hepatitis virus in the  
283        infant mouse. *Jpn J Exp Med* 1979; 49:33-41.
- 284    18. Sebesteny A and Hill AC. Hepatitis and brain lesions due to mouse hepatitis virus  
285        accompanied by wasting in nude mice. *Lab Anim* 1974; 8:317-326.
- 286    19. Report of the Working Group on Hygiene of the Gesellschaft für  
287        Versuchstierkunde-Society for Laboratory Animal Science (GV-SOLAS).  
288        Implications of infectious agents on results of animal experiments. *Lab Anim* 1999;  
289        33 Suppl 1:S39-87.
- 290    20. de Bruin WC, van de Ven EM and Hooijmans CR. Efficacy of soiled bedding

- 291 transfer for transmission of mouse and rat infections to sentinels: A systematic  
292 review. *PLoS One* 2016; 11:e0158410.
- 293 21. Compton SR, Ball-Goodrich LJ, Paturzo FX, et al. Transmission of enterotropic  
294 mouse hepatitis virus from immunocompetent and immunodeficient mice. *Comp*  
295 *Med* 2004; 54:29-35.
- 296 22. Shek WR, Smith AI and Pritchett-Corning TR. Microbiological Quality Control for  
297 Laboratory Rodents and Lagomorphs. In: Fox JG, Anderson LC, Otto GM et al.  
298 (eds) *Laboratory Animal Medicine*. 3<sup>rd</sup> ed. Academic Press 2015, pp463-510.
- 299 23. Becker SD, Bennett M, Stewart JP, et al. Serological survey of virus infection  
300 among wild mouse mice (*Mus domesticus*) in the UK. *Lab Anim* 2007; 41:229-238.
- 301 24. Dammann P, Hilken G, Hueber B, et al. Infectious microorganisms in mice (*Mus*  
302 *musculus*) purchased from commercial pet shops in Germany. *Lab Anim* 2011;  
303 45:271-275.
- 304 25. Hayashimoto N, Morita H, Ishida T, et al. Microbiological survey of mice (*Mus*  
305 *musculus*) purchased from commercial pet shops in Kanagawa and Tokyo, Japan.  
306 *Exp Anim* 2015; 64:155-160.
- 307 26. Kyuwa S. Replication of murine coronaviruses in mouse embryonic stem cell lines  
308 *in vitro*. *Exp Anim* 1997; 46:311-313.

- 309 27. Maherbir E, Bauer B and Schmidt J. Rodent and Germplasm Trafficking: Risks of  
310 microbial contamination in a high-tech biomedical world. *ILAR J* 2008;  
311 49:347-355.
- 312 28. Casebolt DB, Qian B and Stephensen CB. Detection of enterotropic mouse hepatitis  
313 virus fecal excretion by polymerase chain reaction. *Lab Anim Sci* 1997; 47:6-10.
- 314 29. Yamada YK, Yabe M, Takimoto K, et al. Application of nested polymerase chain  
315 reaction to detection of mouse hepatitis virus in fecal specimens during a natural  
316 outbreak in an immunodeficient mouse colony. *Exp Anim* 1998; 47:261-264.
- 317 30. Hanaki K, Ike F, Hatakeyama R, et al. Reverse transcription-loop-mediated  
318 isothermal amplification for the detection of rodent coronaviruses. *J Virol Methods*  
319 2013; 187:222-227.
- 320 31. Barthold SW and Smith AL. Mouse hepatitis virus strain-related patterns of tissue  
321 tropism in suckling mice. *Arch Virol* 1984; 81:103-112.
- 322 32. Barthold SW, Smith AL, Lord PF, et al. Epizootic coronaviral typhlocolitis in  
323 suckling mice. *Lab Anim Sci* 1982; 32:376-383.
- 324 33. Hirano N, Tamura T, Taguchi F, et al. Isolation of low-virulent mouse hepatitis virus  
325 from nude mice with wasting syndrome and hepatitis. *Jpn J Exp Med* 1975;  
326 45:429-432.

- 327 34. Cheever FS and Mueller JH. Epidemic diarrheal disease of suckling mice: I.  
328 manifestations, epidemiology, and attempts to transmit the disease. *J Exp Med*  
329 1947; 85:405-416.
- 330 35. Cheever FS, Daniels JB, Pappenheimer AM, et al. A murine virus (JHM) causing  
331 disseminated encephalomyelitis with extensive destruction of myelin. *J Exp Med*  
332 1949; 90:181-210.
- 333 36. Fleming JO, Trousdale MD, el-Zaatari, et al. Pathogenicity of antigenic variants of  
334 murine coronavirus JHM selected with monoclonal antibodies. *J Virol* 1986; 58:  
335 869–875.
- 336 37. Perlman S, Sun N and Barnett EM. Spread of MHV-JHM from nasal cavity to white  
337 matter of spinal cord. Transneuronal movement and involvement of astrocytes. *Adv*  
338 *Exp Med Biol* 1995; 380:73-78.
- 339 38. Hirano N, Ono K and Matumoto M. Comparison of physicochemical properties of  
340 mouse hepatitis virus strains. *Nihon Juigaku Zasshi* 1989; 51:665-667.
- 341 39. Homberger FR. Sequence analysis of the nucleoprotein genes of three enterotropic  
342 strains of murine coronavirus. *Arch Virol* 1995; 140:571-579.
- 343 40. Yamada YK and Yabe M. Sequence analysis of major structural proteins of newly  
344 isolated mouse hepatitis virus. *Exp Anim* 2000; 49:61-66.

- 345 41. Diekmann O., Heesterbeek JAP and Metz JAJ. On the definition and the  
346 computation of the basic reproduction ratio  $R_0$  in models for infectious diseases in  
347 heterogeneous populations. *J Math Biol* 1990; 28:365–382.
- 348 42. Fraser C, Donnelly CA, Cauchemez S, et al. WHO Rapid Pandemic Assessment  
349 Collaboration. Pandemic potential of a strain of influenza A (H1N1): early findings.  
350 *Science* 2009; 324:1557-1561.
- 351 43. Hirano N, Fujiwara K, Matumoto M. Mouse hepatitis virus (MHV-2). Plaque assay  
352 and propagation in mouse cell line DBT cells. *Jpn J Microbiol* 1976; 20:219-225.
- 353 44. Hirano N, Fujiwara F, Hino S, et al. Replication and plaque formation of mouse  
354 hepatitis virus (MHV-2) in mouse cell line DBT culture. *Arch Gesamte Virusforsch*  
355 1974; 44:298-302.
- 356 45. Delamater PL, Street EJ, Leslie TF, et al. Complexity of the Basic Reproduction  
357 Number ( $R_0$ ). *Emerg Infect Dis* 2019; 25:1-4.
- 358 46. Rehg JE and Toth LA. Rodent quarantine programs: purpose, principles, and  
359 practice. *Lab Anim Sci* 1998; 48:438-447.
- 360 47. Compton SR, Ball-Goodrich LJ, Paturzo FX, et al. Transmission of enterotropic  
361 mouse hepatitis virus from immunocompetent and immunodeficient mice. *Comp*  
362 *Med* 2004; 54:29-35.

- 363 48. Barthold SW and Smith AL. Response of genetically susceptible and resistant mice  
364 to intranasal inoculation with mouse hepatitis virus JHM. *Virus Res* 1987;  
365 7:225-239.
- 366 49. Taguchi F and Fleming JO. Comparison of six different murine coronavirus JHM  
367 variants by monoclonal antibodies against the E2 glycoprotein. *Virology* 1989;  
368 169:233-235.
- 369 50. Lipman NS, Corning BF and Saifuddin M. Evaluation of isolator caging systems  
370 for protection of mice against challenge with mouse hepatitis virus. *Lab Anim* 1993;  
371 27:134-140.
- 372 51. Macy JD, Cameron GA, Ellis SL, et al. Assessment of static isolator cages with  
373 automatic watering when used with conventional husbandry techniques as a factor  
374 in the transmission of mouse hepatitis virus. *Contemp Top Lab Anim Sci* 2002;  
375 41:30-35.
- 376

## 377 **Figure Legends**

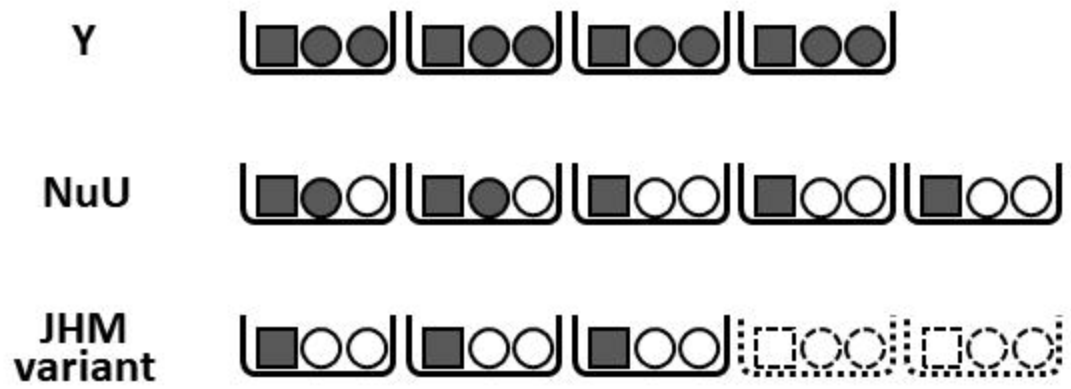
378 **Figure 1.** Transmission of three strains of MHV in mice by cohabitation in a cage. Four,  
379 five, and five B6 mice were inoculated intranasally with either the Y, NuU, or JHM  
380 variant of MHV, respectively. Two days later, each mouse was cohabitated with two  
381 naïve B6 mice in a cage and bred for 4 weeks. Sera were removed, and the anti-MHV  
382 antibody response was examined by ELISA. Grey and white colors indicate a positive  
383 and negative response, respectively. The square and circle indicate the inoculated and  
384 naïve mice, respectively. Since two mice inoculated with the JHM variant had a  
385 negative antibody response (shown by dotted line), data from these cages were excluded  
386 in the calculation of the basic reproduction number.

387

388 **Figure 2.** Viral growth in the organs of mice inoculated with the Y, NuU, and JHM  
389 variants. Viral titers of the brain (a), liver (b), jejunum (c), ileus (d), and colon (e) in  
390 mice inoculated intranasally with the Y (■), NuU (▲), or JHM variant (◻) of MHV was  
391 measured on days 1, 3, and 5 after infection. The horizontal black bar indicates the  
392 average of four samples. The detection limit of MHV in the plaque assay is indicated by  
393 the orange line. □:  $P < 0.05$

394

Figure 1





## Nakayama & Kyuwa Firure 2

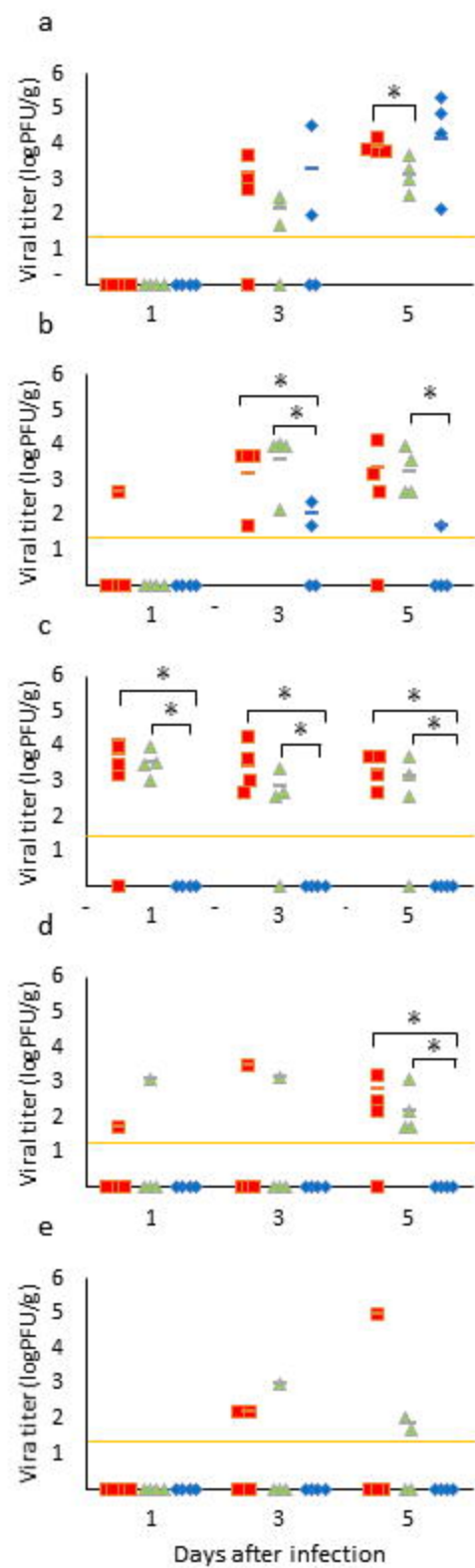


Table 1. Basic reproduction number of three strains of MHV

Viral strain	Basic reproduction number
Y	$\geq 2$
NuU	0.4
JHM variant	0

**Table 2. Detection rates of infectious viruses in various organs in mice inoculated intranasally with three strains of MHV**

Viral strain	Days after infection	Brain	Liver	Jejunum	Ileus	Colon
Y	1	0/5 (0%)*	1/5 (20%)	4/5 (80%)	1/5 (20%)	0/5 (0%)
	3	3/4 (75%)	4/4 (100%)	4/4 (100%)	1/4 (25%)	2/4 (50%)
	5	4/4 (100%)	3/4 (75%)	4/4 (100%)	3/4 (75%)	1/4 (25%)
NuU	1	0/4 (0%)	0/4 (0%)	4/4 (100%)	1/4 (25%)	0/4 (0%)
	3	3/4 (75%)	4/4 (100%)	3/4 (75%)	1/4 (25%)	1/4 (25%)
	5	4/4 (100%)	4/4 (100%)	3/4 (75%)	4/4 (100%)	2/4 (50%)
JHM variant	1	0/4 (0%)	0/4 (0%)	0/4 (0%)	0/4 (0%)	0/4 (0%)
	3	2/4 (50%)	2/4 (50%)	0/4 (0%)	0/4 (0%)	0/4 (0%)
	5	4/4 (100%)	1/4 (25%)	0/4 (0%)	0/4 (0%)	0/4 (0%)

\*Number of samples with infectious virus detected in plaque assay/total number of samples