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***Pseudomonas* Infections in the Common Marmoset (*Callithrix jacchus*): Gross and Histopathological Findings**

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Abstract

Common marmosets (*Callithrix jacchus*) are a New World non-human primate (NHP) whose popularity as a research model continues to expand. Marmosets were identified as the predominant NHP species that is susceptible to spontaneous *Pseudomonas* infections based on a 27-year survey in a primate colony, encompassing several NHP species. Twenty-six common marmosets were retrospectively identified and evaluated for spontaneous *Pseudomonas* spp. infections. Clinical symptoms included lethargy, weight loss, gastrointestinal issues (diarrhea, bloating, vomiting, poor appetite), increased respiratory effort, and difficulty urinating. Affected organs (larynx, lungs, liver, gallbladder, intestines, colon, uterus, and urinary bladder) appeared discolored, distended, or enlarged. Microscopic findings included inflammatory infiltrates, edema, necrosis, hemorrhage, and pseudomembranous lesions. Only animals with clinical symptoms or gross evidence of bacterial infection were cultured; therefore, the actual incidence of *Pseudomonas* spp. infections is unknown. We present the common and uncommon lesions associated with *Pseudomonas* infections in the common marmoset.

Keywords

cholangiohepatitis; cholecystitis; colitis; enteritis; hepatitis; pneumonia; *Pseudomonas*; typhlitis; non-human primate; natural disease; marmoset

Introduction

Pseudomonas aeruginosa is the most common *Pseudomonas* species affecting humans, causing several acute and chronic infections. It is regarded as an opportunistic, nosocomial pathogen known for hepatobiliary tract infections, keratitis, otitis, pneumonia, wound infections, urinary tract infections (UTI), and being the leading cause of death in cystic fibrosis patients. *Pseudomonas* spp. are most often isolated from water and soil. Its versatile characteristics allow it to colonize plants and animals. Contamination of tap water and agricultural soils are traced to be top environmental sources responsible for its transmission.

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The bacterium is regarded as a transient microbe that is not classified as normal flora (Chengappa, Kennedy et al. 2013). Ingestion, inhalation, and direct contact are the primary modes of transmission. Most *P. aeruginosa* infections remain localized with a 50 percent mortality rate (Wagner and Iglewski 2008). In non-human primates (NHPs), spontaneous *Pseudomonas* spp. infections causing notable morbidity or mortality are less common, but NHPs have been used as animal models for *Pseudomonas* antimicrobial and biofilm studies (Dohar, Hebda et al. 2005, Krause, Whu et al. 2013). However, *Pseudomonas* spp. have been cultured in common marmoset investigations relating to gastrointestinal diseases (Shigeno, Toyama et al. 2018, Mineshige, Inoue et al. 2020, Powers, Castell et al. 2023).

Marmosets are a New World NHP whose popularity as a research model has greatly expanded over the last three decades. These arboreal-natured NHP's are characterized by their small body size (300–450 g) and short lifespan (15–16 years), making them cost efficient in biomedical research settings (Han, Powers et al. 2022). Cage enclosure requirements for marmosets are comparatively minimal compared to other NHP species (Pines, Kaplan et al. 2007, Duarte, Goulart et al. 2012). Superior breeding performance in marmosets is demonstrated by their ability to produce nearly three litters every other year with two-to-four offspring per litter for up to seven years of life (Wolfe-Coote 2005).

Within captive settings, marmosets develop spontaneous diseases which present in a broad range of symptoms and diagnoses (David, Dick et al. 2009, Shigeno, Toyama et al. 2018, Fox, Marini et al. 2019, Mineshige, Inoue et al. 2020, Han, Powers et al. 2022, Powers, Castell et al. 2023). Clinical presentations for typical bacterial infections include diarrhea, vomiting, poor appetite, and weight loss. Acute bacterial infections are localized with mild to moderate symptoms associated with the affected organ system, while chronic cases can involve multi-organ lesions and sepsis (Bleyer, Kunze et al. 2017). Herein, we describe the spectrum of spontaneous *Pseudomonas* spp. infections in 26 common marmosets with gross and histopathological findings and a brief note on environmental sources of *Pseudomonas* spp. infection in a marmoset colony.

Materials and Methods

Animals

The common marmoset colony at Southwest National Primate Research Center (SNPRC) has been maintained for breeding and was used in infectious disease, immunology, aging, biocontainment, and neuroscience research during the 27-years covering this case series. Marmosets were housed indoors in conventional wire cages. They were fed commercial monkey chow (Mazuri Callitrichid diet, Richmond, IN, USA) and supplemented with grains, fruits, and vegetables. Water was available *ad libitum*. All procedures were approved by the SNPRC Institutional Animal Care and Use Committee (IACUC).

Case selection

A search of *Pseudomonas* spp. as etiology in common marmoset (*Callithrix jacchus*) necropsy and clinical records was performed using SNPRC's animal database. The search identified 41 culture positive *Pseudomonas* cases. Case selection criteria for this series

included a requirement of necropsy report, an abundant *Pseudomonas* spp. culture result, and associated pathology of the bacterial infection. 26 cases were selected based on these criteria. None of the marmosets reported in this case series were used in research projects that would have an impact on their likelihood of acquiring *Pseudomonas* spp.

Necropsy and histopathology

Necropsy and histopathology evaluation of marmosets that were found dead or euthanized were performed by board-certified veterinary pathologists. Tissues were fixed in 10% neutral buffered formalin, processed conventionally, embedded in paraffin, sectioned at 5µm, stained with hematoxylin and eosin (H&E), and in some cases, Gram stain.

Microbiological analysis

Samples for bacterial identification were collected antemortem and/or postmortem. In antemortem collections, samples were taken when the marmoset experienced clinical symptoms indicating a gastrointestinal infection (diarrhea, bloating, weight loss) or at the site of a present abscess. During necropsy, postmortem cultures were collected from the larynx, lung, gallbladder, liver, intestinal tract, colon, and uterus when the organ presented gross appearance of an infection. Bacterial identification was performed by in-house or referral laboratories by culture or PCR assays that were developed and modified based on *oprL* and *gyrB* primers and probe sets from Le Gall et al., 2013 (Le Gall, Le Berre et al. 2013). Environmental sampling including but not limited to cages, food, and water was performed to identify the source of bacterial infection during one of the recent spikes in *Pseudomonas* infections.

Results

Retrospective analysis of case records

Over the 27-year (1996–2023) period of this case series search for *Pseudomonas* spp. infections at SNPRC, all positive cultures were from marmosets, except for one positive baboon culture. Twenty-six marmosets had *Pseudomonas* spp. positive cultures at the time of necropsy with associated histopathologic indicators of the infection (Figure 1). In 14 cases, *Pseudomonas* spp. was the only cultured bacteria from the culture site, while 12 cases presented mixed bacterial cultures with *Pseudomonas* spp. (Table 1). Marmosets ranged from infants (as young as four months) to geriatric (up to 146 months) animals in which 17 (65%) were female, and nine (35%) were male. Twelve marmosets were found dead in their cages, 13 marmosets were euthanized due to clinical symptoms, and one marmoset (Case 15) did not recover from procedure-related anesthesia. Demographic characteristics are outlined in Table 2.

Pathological findings of *Pseudomonas* infections in marmosets

All affected marmosets presented with gross lesions which included purulent exudate, fibrinous to fibrous adhesions, hemorrhage, mucosal thickening, organomegaly, and abscessation. Gross appearance of organs prompted culture samples to be taken during necropsy. *Pseudomonas* infections were primarily seen in the digestive system (small and

large intestine, liver, gallbladder), followed by respiratory (lungs and larynx), and urogenital (urinary bladder and uterus).

Peritoneal cavities occasionally contained yellow fluid, gastrointestinal enlargement and discoloration with or without serosal fibrinous material (Figure 2A) was the most common observation with 20 marmosets affected. Stomachs were usually empty, and colons contained liquid stool. Dilation, red infarcts, and mucosal adhesions were marked diffusely throughout ceca and colons. Firm masses, plaque-like lesions or raised abscesses were identified in the gallbladder, pancreas, cecum, and colon (Figure 2B). Gallbladders were dilated with thickened walls and contained green-tan bile or pale-yellow purulent material. Liver lesions ranged from pale tan to mottled red-dark areas, sometimes with yellow fibrinous material adherent to the lobes (Figure 2A, 2C). Affected livers were mild to severely enlarged. Histopathological diagnoses encompassing the digestive system appeared in 22 cases. Histologically, colitis (n=14), cholecystitis (n=13), and typhlitis (n=10) were the most frequent morphologic diagnoses (Table 2). Tubular digestive organs (esophagus, stomach, intestines, gallbladder, and colon) showed cellular debris-filled lumen areas, sometimes admixed with bacteria. There was often transmural thickening by edema, pseudomembranous fibrin, necrotized tissue, and ulcerations. Varying degrees of suppurative inflammation with lymphocytes, macrophages, and plasma cells was observed in the mucosa, submucosa, and serosa. Portal areas were frequently expanded as a result of bridging fibrosis and edema (Figure 3A to 3E).

Three marmosets presented with pneumonia, one of which also presented with a thickened larynx. These lungs failed to deflate and had a firm, wet appearance. Lung lobes were regionally red to dark red, sometimes with red-pink mottling (Figure 2D, 2E) Histologically, there was diffuse hemorrhagic pneumonia and bacterial aggregates were frequently seen along necrotic alveolar septa and bronchi (Figure 3F). In the laryngitis case, the mucosa and submucosa were necrotic and infiltrated with inflammatory cells.

Two marmosets had enlarged uteri with yellow to tan discoloration transmurally (Figure 2F). Necrotic material was found in the uterine lumens when opened. The metritis cases histologically presented with fibrin, necrotic debris, hemorrhage, and suppurative inflammation admixed with bacteria. In one marmoset, the urinary bladder displayed moderate hemorrhage grossly (Figure 2F) and histologically within its wall (not shown). A range of renal changes were observed in 15 marmosets; however, renal disease is a common background finding in marmosets (David, Dick et al. 2009, Lee, Gonzalez et al. 2019). None of the kidneys were cultured positive for *Pseudomonas* and lesions consistent with bacterial infection were not identified. These will not be discussed further.

Microbial analysis

Fourteen of the 26 postmortem cultures returned *Pseudomonas* spp. as single isolates and the remaining 12 cultures gave bacterial combination results (Table 1). Nineteen of the 26 cultures specifically yielded *Pseudomonas aeruginosa*; the other seven were not speciated and only identified as *Pseudomonas* spp. Investigation of the source of infection during one of the recent spikes in cases involved testing of drinking water sources, food, cage and other environmental surfaces by PCR testing. Sources of drinking water including

drinking bottles and kitchen sinks were found to be the primary sources of *Pseudomonas* infection. Replacement of water filters and bottles along with changes in disinfection methods mitigated the increased number of *Pseudomonas* infections in the marmoset colony.

Discussion

The common marmoset has become an attractive animal model in biomedical research due to complete sequencing of their genome and physiological likeness to humans. Growth, metabolic, reproductive and immunity pathways have been positively observed as a result of the sequencing, enabling comparative analyses with Old World primates and humans (Worley, Warren et al. 2014). Additionally, the short lifespan of marmosets offers researchers the ability to observe complete aging-related and neurological degenerative disease progression. Biocontainment infectious diseases research on marmosets has been proven to appropriately mimic human disease progression and pathophysiology for several infectious agents (Artim, Sheh et al. 2019, Nelson, Salguero et al. 2021). However, only mild responses were displayed in some experimental infections, such as COVID-19 (Han, Powers et al. 2022). Marmosets have shown greatest homology with immunoglobulins and T-cell receptors of humans, making them relevant in immune toxicological research (Nelson and Loveday 2014).

Routinely reported bacterial species isolated from marmosets include *Campylobacter* spp., *Clostridium* spp., *Escherichia coli*, *Francisella tularensis*, *Helicobacter* spp., *Klebsiella* spp., *Pseudomonas* spp., *Shigella* spp., and *Staphylococcus* spp. *Pseudomonas* spp. are gram-negative bacilli that are environmentally ubiquitous. They cause acute and chronic persistent infections by quickly adapting to environmental changes (Lorenz, Pawar et al. 2016).

Pseudomonas spp. cause successful infections due to a variety of virulence factors contributing to host cell attachment, immune response inhibition, and antibiotic resistance (Qin, Xiao et al. 2022). Its polar flagella enable the pathogen to swim to epithelial surfaces where their flagella will transition into an irreversible attachment mechanism (Kazmierczak, Schniederberend et al. 2015). Exotoxin secretion systems, along with a highly impermeable lipopolysaccharide (LPS) outer membrane and biofilm shield, are key features for *Pseudomonas*' intrinsic resistance against multiple antibiotics (Lorenz, Pawar et al. 2016).

The NHP colony at SNPRC is primarily composed of baboons, rhesus macaques, cynomolgus macaques, marmosets, and few chimpanzees. Over the 27-year period of analysis of case reports for *Pseudomonas* infections, other than marmosets only one baboon was reported to have *Pseudomonas* spp. infection. This could be indicative of higher susceptibility of marmosets to *Pseudomonas* infection or maybe the differences in housing (indoor, smaller cages, etc.) may influence the survival of *Pseudomonas* in the environment and result in greater number of cases. Since only animals with clinical symptoms or gross evidence of bacterial infection were cultured during necropsy procedures, the actual incidence of *Pseudomonas* spp. infections at SNPRC is likely higher and this study is not indicative of true morbidity and mortality rates caused by *Pseudomonas* spp. in captive marmoset populations. Clinical presentations of bacterial infections included

lethargy, gastrointestinal issues (diarrhea, bloating, vomiting, weight loss, poor appetite), increased respiratory effort, and difficulty urinating. Gross lesions were observed in one or more organs during necropsy. Affected organs (larynx, lungs, liver, gallbladder, intestines, colon, uterus, and urinary bladder) appeared discolored, distended, enlarged, and/or with necrotic material. Microscopic findings varied in severity and confirmed the presence of inflammatory infiltrates, edema, necrotic material, hemorrhage, and pseudomembranous lesions. Upon examination, tubular digestive organs (cecum, intestines, and colon) displayed mild to severe regions of inflammatory infiltrates, edema, and necrosis. The mucosal layers showed greatest degrees of necrosis, ulceration, and fibrin deposits. Lymphocytes, plasma cells, and neutrophils were most often observed in the lamina propria. Submucosal and muscularis layers were marked with edema and inflammatory infiltrates. Some chronic cases presented with transmural edema, necrosis, fibrin, and infiltrates. Livers and gallbladders were often diagnosed with hepatitis, cholecystitis and cholangiohepatitis, indicating an ascending infection occurred. Portal areas of the liver were frequently expanded by edema and low numbers of inflammatory cells. However, variable numbers of neutrophils were contained in the hepatic lobes and admixed with fibrin deposits. Gallbladder infections developed with or without liver infections. Gallbladder lumens were filled with suppurative inflammation or necrotic material, and lymphocyte follicular formations were observed throughout the wall. Epithelial hyperplasia and ulceration were frequently present. Transmural inflammation from epithelium to the submucosal layers affirmed lesion chronicity in severe cases. The lesions in the tubular organs are similar to other bacterial infections including *Francisella tularensis*, *Yersinia* spp., and *Helicobacter* spp. *Shigella* spp. that cause necrotizing, hemorrhagic, and ulcerating typhlitis. Colonic mucosal surfaces and crypts were observed to undergo structural changes including hyperplasia, sloughing, edema, ulceration, and necrosis when infected with *Klebsiella* spp., *Clostridium* spp., *Shigella* spp., *Escherichia coli*, and *Helicobacter* spp. Hepatic lesions, including hepatic necrosis and inflammation, are regularly observed in *Clostridium* spp., *Yersinia* spp., and *Francisella tularensis* infections (Fox, Marini et al. 2019).

Literature on *Pseudomonas* spp. infections in NHPs is limited; few reports involving marmosets were identified. Marmosets are known for presenting gastrointestinal issues in captive settings, prompting investigations into factors influencing digestive disease outbreaks. Previously, five marmosets were reported with proliferative cholecystitis and severe, necrosuppurative cholangiohepatitis which was accompanied by positive *Pseudomonas aeruginosa* cultures (Powers, Castell et al. 2023). The accompanied histopathological findings included bile duct hyperplasia, periportal hepatitis, bile peritonitis, ulcerative gastroenteritis, and typhlitis (Powers, Castell et al. 2023), similar to the lesions reported in this study. Two other research institutes sought to identify causative agents for the gastrointestinal issues experienced by their marmosets. They concluded that *Pseudomonas* spp. may be a contributing factor for chronic diarrhea, bloating, and weight loss (Shigeno, Toyama et al. 2018, Mineshige, Inoue et al. 2020).

Pneumonia cases in the present study displayed alveolar spaces filled with abundant erythrocytes, proteinaceous fluid, and alveolar macrophages. Alveolar septa and bronchi were necrotic and occasionally covered by *Pseudomonas* spp. bacterial aggregates. *Francisella tularensis*, *Bordetella* spp., and *Klebsiella* spp. are also known to affect

the respiratory system resulting in similar lesions of interstitial pneumonia and bronchopneumonia (Bleyer, Kunze et al. 2017, Fox, Marini et al. 2019). Both cases of metritis in the present study had transmural suppurative inflammation of the uterus with lumens occupied by fibrin, hemorrhage, necrotic debris, and neutrophils. Two other bacterial species reported to cause urogenital infections in NHPs are *Staphylococcus* spp. and *Helicobacter* spp. (Fox, Marini et al. 2019). *Staphylococcus* spp. has been cultured from the vagina and penis. Infections with *Helicobacter* spp. had reported pathological changes including glomerular and interstitial nephritis. Other urogenital diseases implicated to result from bacterial agents include glomerulosclerosis, tubular lesions, and renal failure (Fox, Marini et al. 2019). Only one marmoset from our dataset had *Pseudomonas* spp. cultured from a large external abdominal wound. Nonetheless, skin infections should be regarded as an atypical presentation in marmosets.

Several infections presented microscopically with bacterial colonies admixed with necrotic, fibrinous, or hemorrhagic material. Gram-stained slides demonstrated clusters of gram-negative bacilli bacteria consistent with *Pseudomonas* spp. (not shown). Not all cases had Gram stains performed, but dense bacilli bacterial colonies were observed in H&E slides. For cases with polymicrobial culture results (Table 1), the *Pseudomonas* spp. bacterial colonies were most abundant. This aligns with Lorenz et al.'s review on animal model responses to *Pseudomonas aeruginosa* during polymicrobial studies (Lorenz, 2016 #27).

Pseudomonas spp. contamination of tap water is a major source of infection. Tap water contamination may be a result of tap fixtures becoming colonized with the bacterium as it exists in protective biofilms (Whitacre 2009). In our case study, a recent spike in *Pseudomonas* spp. infections in the marmosets could be attributed to the drinking water source since some of the investigated drinking bottles tested positive for the bacteria. In addition to direct ingestion of the tap water, *Pseudomonas* spp. can be found on medical equipment (endotracheal tubes, laryngoscopes, bronchoscopes) if washed and rinsed with contaminated tap water. Moreover, contaminated water sources and dampened feces may become pathogenic aerosols through evaporation and humidity that can cause infection from inhalation. Chlorine, chloramines, ozone, and iodine have proven to be effective water treatments against *Pseudomonas* spp. (Whitacre 2009). Powers et al. (2023) reported a failed drinking water chlorination system to be the identified source of *Pseudomonas* spp. infections in five of seven diseased marmosets.

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Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

- Artim SC, Sheh A, Burns MA and Fox JG (2019). "Evaluating rectal swab collection method for gut microbiome analysis in the common marmoset (*Callithrix jacchus*)." *PloS one* 14(11): e0224950–e0224950. [PubMed: 31697779]
- Bleyer M, Kunze M, Gruber-Dujardin E and Mätz-Rensing K (2017). "Spontaneous lung pathology in a captive common marmoset colony (*Callithrix jacchus*)." *Primate Biology* 4(1): 17–25. [PubMed: 32110688]
- Chengappa MM, Kennedy M and McVey DS (2013). *Veterinary microbiology*. Iowa, U.S.A, Wiley-Blackwell.
- David JM, Dick EJ and Hubbard GB (2009). "Spontaneous pathology of the common marmoset (*Callithrix jacchus*) and tamarins (*Saguinus oedipus*, *Saguinus mystax*)." *J Med Primatol* 38(5): 347–359. [PubMed: 19522731]
- Dohar JE, Hebda PA, Veeh R, Awad M, Costerton JW, Hayes J and Ehrlich GD (2005). "Mucosal biofilm formation on middle-ear mucosa in a nonhuman primate model of chronic suppurative otitis media." *Laryngoscope* 115(8): 1469–1472. [PubMed: 16094127]
- Duarte MHL, Goulart VDLR and Young RJ (2012). "Designing laboratory marmoset housing: What can we learn from urban marmosets?" *Applied animal behaviour science* 137(3–4): 127–136.
- Fox JG, Marini RP, Wachtman LM, Tardif SD and Mansfield K (2019). *The common marmoset in captivity and biomedical research*. London, England, Academic Press.
- Han H-J, Powers SJ and Gabrielson KL (2022). "The Common Marmoset—Biomedical Research Animal Model Applications and Common Spontaneous Diseases." *Toxicologic pathology* 50(5): 628–637. [PubMed: 35535728]
- Kazmierczak BI, Schniederberend M and Jain R (2015). "Cross-regulation of *Pseudomonas* motility systems: the intimate relationship between flagella, pili and virulence." *Current opinion in microbiology* 28: 78–82. [PubMed: 26476804]
- Krause A, Whu WZ, Qiu J, Wafadari D, Hackett NR, Sharma A, Crystal RG and Worgall S (2013). "RGD capsid modification enhances mucosal protective immunity of a non-human primate adenovirus vector expressing *Pseudomonas aeruginosa* OprF." *Clinical and experimental immunology* 173(2): 230–241. [PubMed: 23607394]
- Le Gall F, Le Berre R, Rosec S, Hardy J, Gouriou S, Boisrame-Gastrin S, Vallet S, Rault G, Payan C and Hery-Arnaud G (2013). "Proposal of a quantitative PCR-based protocol for an optimal *Pseudomonas aeruginosa* detection in patients with cystic fibrosis." *BMC Microbiol* 13: 143. [PubMed: 24088260]
- Lee HJ, Gonzalez O, Dick EJ, Donati A, Feliers D, Choudhury GG, Ross C, Venkatachalam M, Tardif SD and Kasinath BS (2019). "Marmoset as a Model to Study Kidney Changes Associated With Aging." *The journals of gerontology. Series A, Biological sciences and medical sciences* 74(3): 315–324. [PubMed: 30321310]
- Lorenz A, Pawar V, Häussler S and Weiss S (2016). "Insights into host–pathogen interactions from state-of-the-art animal models of respiratory *Pseudomonas aeruginosa* infections." *FEBS letters* 590(21): 3941–3959. [PubMed: 27730639]
- Mineshige T, Inoue T, Yasuda M, Yurimoto T, Kawai K and Sasaki E (2020). "Novel gastrointestinal disease in common marmosets characterised by duodenal dilation: a clinical and pathological study." *Scientific reports* 10(1): 3793–3793. [PubMed: 32123196]
- Nelson M and Loveday M (2014). "Exploring the Innate Immunological Response of an Alternative Nonhuman Primate Model of Infectious Disease; the Common Marmoset." *Journal of immunology research* 2014: 913632–913638. [PubMed: 25170519]
- Nelson M, Salguero FJ, Hunter L and Atkins TP (2021). "A Novel Marmoset (*Callithrix jacchus*) Model of Human Inhalational Q Fever." *Frontiers in cellular and infection microbiology* 10: 621635–621635. [PubMed: 33585288]
- Pines MK, Kaplan G and Rogers LJ (2007). "A note on indoor and outdoor housing preferences of common marmosets (*Callithrix jacchus*)." *Applied animal behaviour science* 108(3): 348–353.

- Powers SJ, Castell N, Vistein R, Kalloo AN, Izzi JM and Gabrielson KL (2023). “Bacterial Cholecystitis and Cholangiohepatitis in Common Marmosets (*Callithrix jacchus*).” *Comparative medicine* 73(2): 173–180. [PubMed: 36944497]
- Qin S, Xiao W, Zhou C, Pu Q, Deng X, Lan L, Liang H, Song X and Wu M (2022). “*Pseudomonas aeruginosa*: pathogenesis, virulence factors, antibiotic resistance, interaction with host, technology advances and emerging therapeutics.” *Signal transduction and targeted therapy* 7(1): 199–199. [PubMed: 35752612]
- Shigeno Y, Toyama M, Nakamura M, Niimi K, Takahashi E and Benno Y (2018). “Comparison of gut microbiota composition between laboratory-bred marmosets (*Callithrix jacchus*) with chronic diarrhea and healthy animals using terminal restriction fragment length polymorphism analysis.” *Microbiology and immunology* 62(11): 702–710. [PubMed: 30350387]
- Wagner VE and Iglewski BH (2008). “*P. aeruginosa* Biofilms in CF Infection.” *Clinical reviews in allergy & immunology* 35(3): 124–134. [PubMed: 18509765]
- Whitacre DM (2009). *Reviews of Environmental Contamination and Toxicology* 201. New York, NY, Springer US.
- Wolfe-Coote S (2005). *The laboratory primate*. Amsterdam, Elsevier Academic Press.
- Worley KC, Warren WC, Rogers J, Locke D, Muzny DM, Mardis ER, Weinstock GM, Tardif SD, Aagaard KM, Archidiacono N, Arul Rayan N, Batzer MA, Beal K, Brejova B, Capozzi O, Casola C, Chandrabose MM, Cree A, Diep Dao M, De Jong PJ, Cruz-Herrera del Rosario R, Delehaunty KD, Dinh HH, Fitzgerald S, Flicek P, Fontenot CC, Fowler RG, Fronick C, Fulton RS, Gabisi RA, Gerlach D, Graves TA, Gunaratne PH, Hahn MW, Haig D, Han Y, Harris RA, Herrero J, Hillier LW, Hubley R, Hughes JF, Hume J, Jhangiani SN, Jorde LB, Joshi V, Karakor E, Konkel MK, Kosiol C, Lkovar C, Kriventseva EV, Lee SL, Lewis LR, Liu Y-S, Lopez J, Lorente-Galdos B, Mansfield KG, Marques-Bonet T, Minx P, Moncrieff JS, Morgan MB, Nazareth LV, Newsham I, Nguyen NB, Okwuonu GO, Prabhakar S, Perales L, Pu L-L, Puente XS, Quesada V, Ranck MC, Raney BJ, Raveendran M, Rocchi M, Rodriguez D, Ross C, Ruffier M, Ruiz SJ, Sajjadian S, Santibanez J, Schrider DR, Searle S, Soibam B, Tennakoon JB, Tomaska L, Ullmer B, Vejnar CE, Ventura M, Vilella AJ, Vinar T, Walker JA, Wang Q, Warner CM, Wildman DE, Wu Y, Xiao W, Xing J, Zdobnov EM, Zhu B, Gibbs RA and Wilson RK (2014). “The common marmoset genome provides insight into primate biology and evolution.” *Nature genetics* 46(8): 850–857. [PubMed: 25038751]

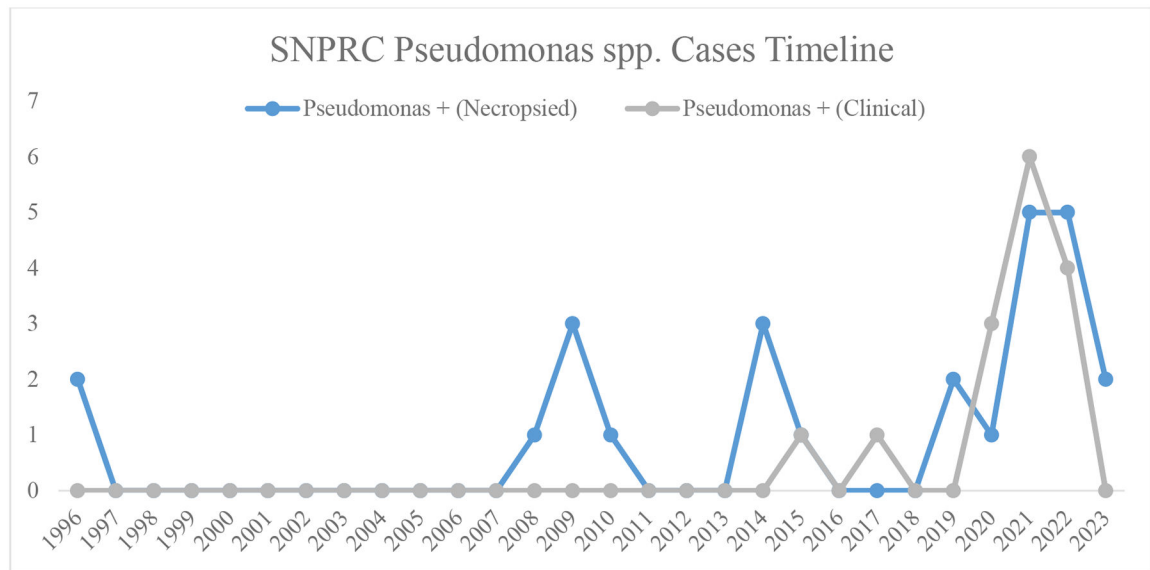


Figure 1.

Timeline of *Pseudomonas* spp. positive cultures. 41 total *Pseudomonas* spp positive. cases in marmosets were identified between 1996 and 2023 at Southwest National Primate Research Center (SNPRC). 26 cultures were taken at the time of necropsy and are represented by the blue line. 15 cultures were taken when clinical symptoms were indicative of a bacterial infection shown as the grey line.

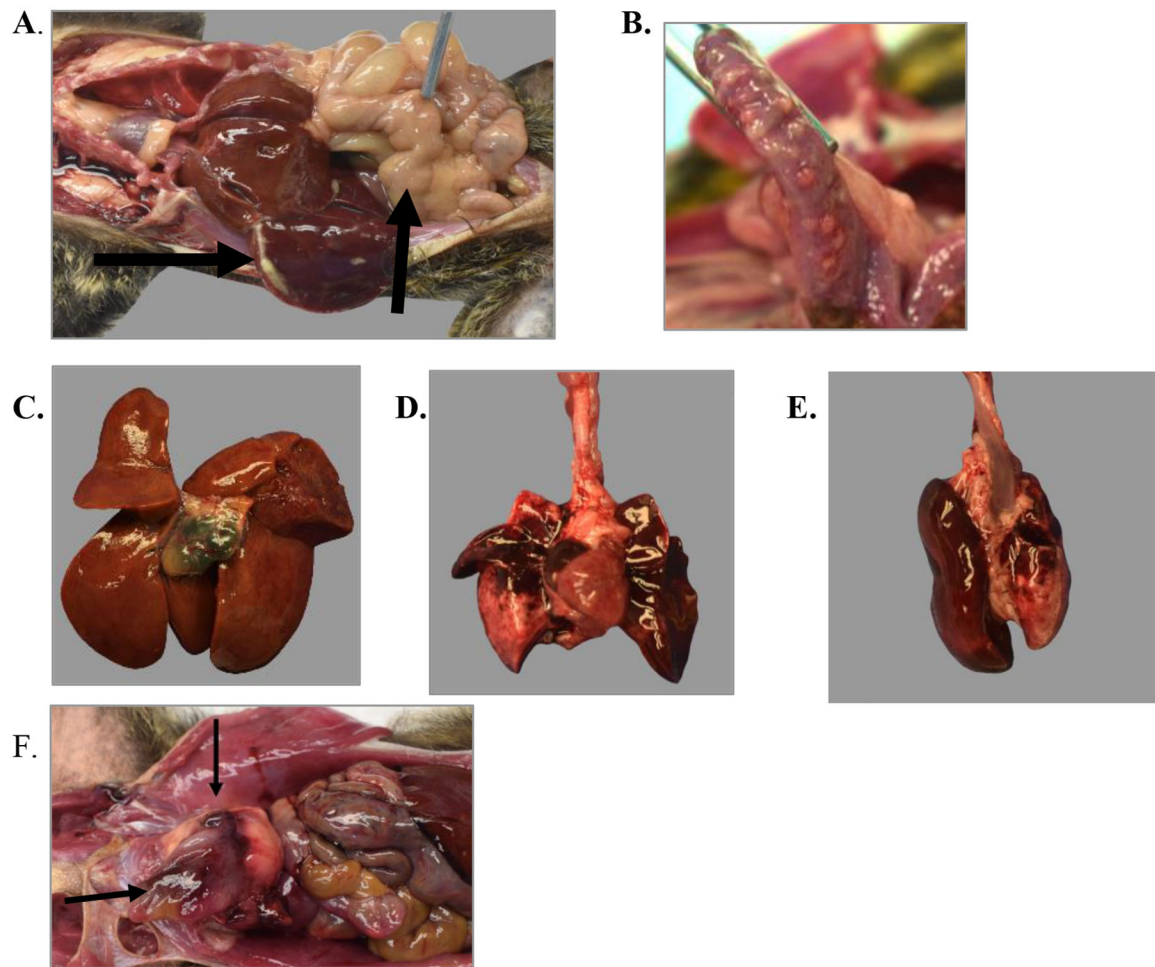


Figure 2.

Gross lesions of *Pseudomonas* spp infection in common marmosets. (A) Arrows point to fibrin on the liver and scant yellow fluid in the peritoneal cavity. The colon is distended and yellow with a thickened wall (metal probe holding it). (B) Cecum. There are multifocal, 2–3mm diameter, raised, areas on the serosal surface. Some appear to contain fluid and others appear solid. (C) Liver and gallbladder. The gallbladder is dilated with a diffuse edematous wall. Areas of yellow-tan hepatic parenchyma is consistent with inflammation. (D) Lung. Hemorrhagic pneumonia. Entire left lung, and portions of the right upper and middle lung lobes are diffusely dark red and firm. The right lower lung lobe was pink-red mottled. (E) Lung. Hemorrhagic pneumonia. Entire left lung and right upper portions are diffusely dark red. (F) Uterus. Metritis. The uterus is indicated by the vertical arrow and is markedly enlarged, and yellow-tan transmurally. The urinary bladder lays on top of the uterus, shown by the horizontal arrow, and displays edema and hemorrhage of the wall.

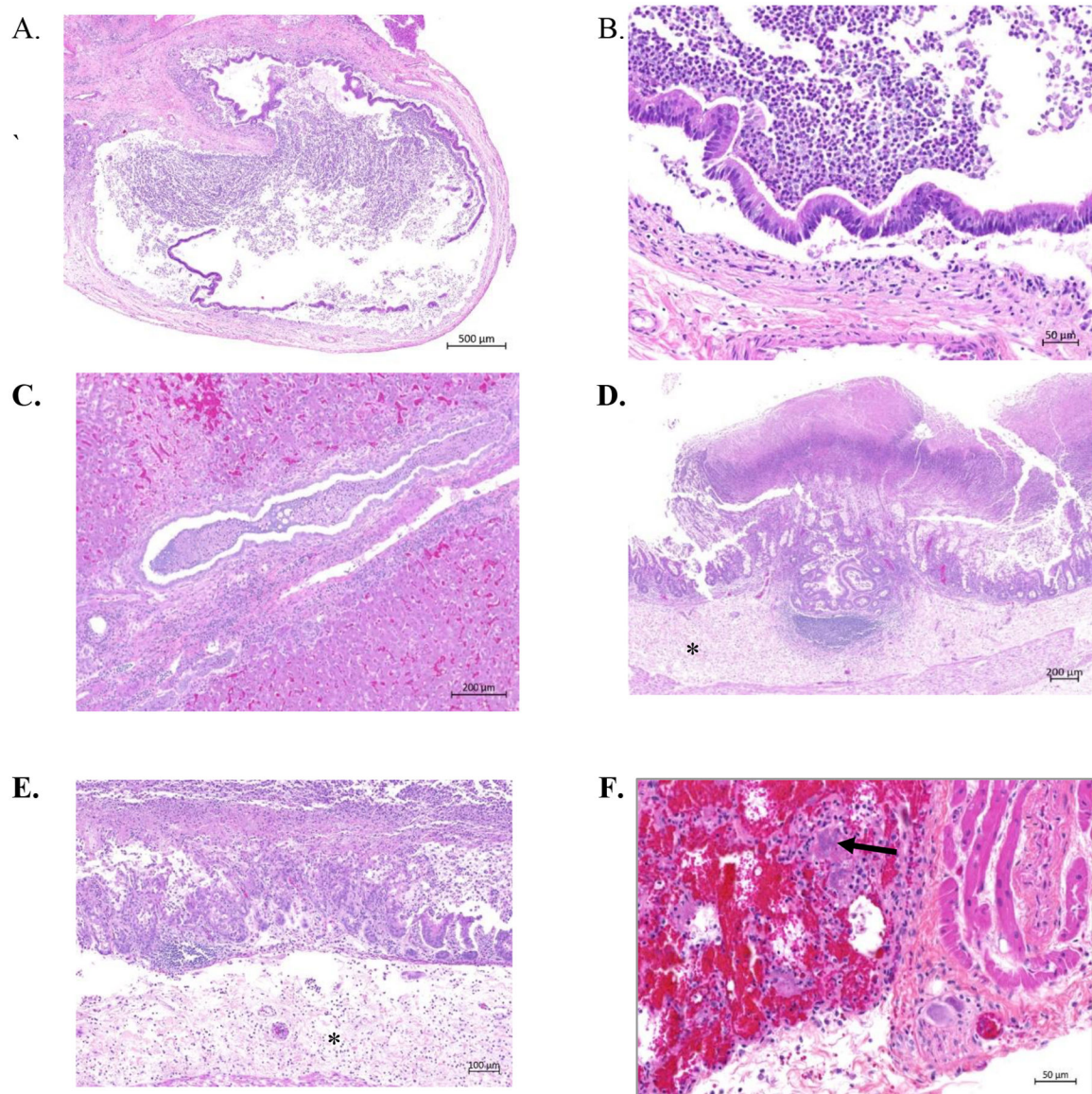


Figure 3.

Histopathological lesions of gastrointestinal system caused by *Pseudomonas* spp infection. A. and B. Gallbladder showing marked infiltration of neutrophils and macrophages admixed with bacterial aggregates within the lumen and mucosa. There is mild edema and infiltration of lymphocytes within the wall of the gall bladder. C. Liver: portal areas showing bile duct lumen with degenerate neutrophils and cellular debris. Portal areas are infiltrated with neutrophils, lymphocytes and plasma cells. There is mild periportal hepatocellular necrosis. D. Cecum showing marked submucosa edema, GALT hyperplasia with necrosis, mucosa ulceration covered with necrotic debris, degenerate neutrophils and bacterial aggregates. E. Colon showing marked submucosal edema (*), crypt necrosis overlaid with necrotic debris and abundant degenerate neutrophils. F. Lung showing marked alveolar hemorrhage, alveolar septal necrosis and occasional bacterial aggregates (arrow).

Table 1.

Results of the microbial culture and the different sites from which the samples were collected. Cultures from 14 animals resulted in solely *Pseudomonas* spp. growth; cultures from 12 animals had mixed bacterial infections with abundant *Pseudomonas* spp. growth.

Case No.	Culture Site	Culture Results
1	Colon	<i>Pseudomonas aeruginosa</i>
2	Colon	1) <i>Enterococcus faecalis</i> 2) <i>Pseudomonas aeruginosa</i>
3	Colon	<i>Pseudomonas aeruginosa</i>
4	Colon	<i>Pseudomonas aeruginosa</i>
5	Colon	<i>Pseudomonas aeruginosa</i>
6	Larynx	<i>Pseudomonas aeruginosa</i>
	Lung	<i>Pseudomonas aeruginosa</i>
7	Lung	1) <i>Escherichia coli</i> 2) <i>Pseudomonas</i> spp.
8	Liver	1) <i>Enterococcus</i> spp. 2) <i>Pseudomonas aeruginosa</i>
9	Gallbladder	<i>Pseudomonas aeruginosa</i>
10	Gallbladder	<i>Pseudomonas aeruginosa</i>
11	Abdominal Skin ulceration	<i>Pseudomonas aeruginosa</i>
12	Colon	1) <i>Escherichia coli</i> 2) <i>Klebsiella</i> spp. 3) <i>Pseudomonas</i> spp.
13	Liver	<i>Pseudomonas aeruginosa</i>
14	Colon	<i>Pseudomonas aeruginosa</i>
15	Gallbladder	<i>Pseudomonas</i> spp.
16	Colon	1) <i>Escherichia coli</i> 2) <i>Enterococcus</i> spp. 3) <i>Pseudomonas</i> spp.
17	Colon	1) <i>Escherichia coli</i> 2) <i>Enterococcus</i> spp. 3) <i>Pseudomonas aeruginosa</i>
18	Liver	<i>Pseudomonas aeruginosa</i>
19	Colon	1) <i>Escherichia coli</i> 2) <i>Enterococcus</i> spp. 3) <i>Pseudomonas aeruginosa</i>
20	Colon	1) <i>Escherichia coli</i> 2) <i>Enterococcus</i> spp. 3) <i>Pseudomonas aeruginosa</i>
21	Uterus	1) <i>Escherichia coli</i> 2) <i>Pseudomonas</i> spp.
22	Cecum	1) <i>Enterococcus</i> spp. 2) <i>Pseudomonas aeruginosa</i>
23	Gallbladder	<i>Pseudomonas</i> spp.
	Peritoneal cavity	<i>Pseudomonas</i> spp.
24	Gallbladder	1) <i>Enterococcus</i> spp., 2) <i>Pseudomonas aeruginosa</i>
25	Peritoneal cavity	1) <i>Enterococcus</i> spp. 2) <i>Pseudomonas</i> spp.
26	Lung	<i>Pseudomonas aeruginosa</i>

Table 2.

Demographics of necropsied marmosets selected in this case series and their corresponding histopathological diagnoses.

Case No.	Death Type	Death Date	Age at Death (months)	Sex	Histopathological Diagnoses
1	Died	1996-03-15	40	M	Hepatitis, typhlitis
2	Euthanized	1996-10-23	98	M	Colitis, glomerulonephritis, lipidosis, peritonitis
3	Died	2008-05-22	28	F	Cholecystitis, gastroenterocolitis, hepatitis, pyelonephritis
4	Died	2009-09-05	7	M	Colitis, typhlitis
5	Died	2009-10-21	11	F	Colitis, thrombosis
6	Euthanized	2009-11-13	14	F	Laryngitis, lipidosis, pneumonia
7	Died	2010-01-24	8	F	Colitis, pneumonia, nephritis
8	Died	2014-05-21	84	M	Cholangiohepatitis, cholecystitis, nephritis, thrombosis
9	Euthanized	2014-06-18	114	F	Cholangiohepatitis, cholecystitis, colitis, nephritis
10	Died	2014-07-22	129	F	Cholangiohepatitis, cholecystitis, choledochitis, colitis, enteritis, nephropathy
11	Euthanized	2015-03-24	26	F	Nephritis, skin ulceration
12	Died	2019-04-22	17	F	Colitis, enteritis, typhlitis
13	Euthanized	2019-12-06	55	F	Cholecystitis, hepatitis, splenitis
14	Euthanized	2020-11-03	50	F	Cholecystitis, colitis, enteritis, gastritis, hepatitis, metritis, nephritis, oophoritis, thyroiditis, typhlitis
15	Died	2021-02-04	106	M	Cholecystitis, hepatitis
16	Euthanized	2021-04-05	4	F	Colitis, typhlitis
17	Euthanized	2021-04-05	4	F	Colitis, typhlitis
18	Died	2021-08-16	86	M	Cholecystitis, colitis, enteritis, esophagitis, hepatitis, lymphadenitis, nephritis
19	Euthanized	2021-09-17	59	M	Colitis, enteritis, hepatitis, nephritis, typhlitis
20	Euthanized	2022-01-18	24	F	Cholangiohepatitis, cholecystitis, colitis, nephritis, peritonitis, typhlitis
21	Died	2022-04-24	49	F	Adrenitis, metritis, nephritis
22	Euthanized	2022-07-26	62	M	Cholecystitis, enteritis, nephritis, typhlitis
23	Euthanized	2022-09-16	52	F	Cholecystitis, enteritis, nephritis, peritonitis
24	Euthanized	2022-11-14	82	M	Cholecystitis, hepatitis, nephritis
25	Died	2023-01-29	146	F	Cholecystitis, enteritis, goiter, hepatitis, nephritis, peritonitis, typhlitis
26	Died	2023-05-22	4	F	Lipidosis, lymphadenitis, pneumonia