Pigeon Paramyxovirus-1 Infection and the Public Health Importance: A Review Article

Wafaa A. Abd El-Ghany
Poultry Diseases Department, Faculty of Veterinary Medicine, Cairo University, 12211, Giza, Egypt

Keywords: *Newcastle disease or paramyxovirus, clinical picture, pigeon, human, vaccination*

Abstract. *Pigeons are highly susceptible to Newcastle disease virus (NDV) infection, which causes economic losses in terms of increased mortalities, immunosuppression, vaccination costs, and probable trade restrictions. NDV belongs to the avian paramyxovirus serotype 1 (APMV-1). The antigenic variant of APMV-1 is termed as pigeon paramyxovirus type 1 (PPMV-1), which is classified in the genus Avulavirus of the subfamily Paramyxovirinae and family Paramyxoviridae. Infections of pigeons with PPMV-1 have been detected since the 1930s, and the virus is still circulating in many countries until now. Domestic, feral, and racing pigeons, doves, and exotic birds are susceptible to PPMV-1 infection. The virus is rapidly spreading between birds through the horizontal route. Infected pigeons may show circling, ataxia, torticollis, head and neck tremors and twisting, leg and wing paralysis, greenish diarrhea, respiratory signs, and polyuria. Some pigeons could be infected with PPMV-1 without apparent signs, and they act as reservoirs for other domestic or free-living birds. The diagnosis of suspected PPMV-1 cases is based mainly on the isolation and identification of the virus, serological detection of specific antibodies, and molecular characterization of the virus. Adoption of strict biosecurity measures as well as vaccination using traditional live or inactivated NDV or even the specific PPMV-1 vaccines are the gold standard methods for preventing pigeons from such infection. Therefore, this review article was designed to focus on PPMV-1 infection regarding the virus characteristics, epidemiology, diagnosis, human infection, and control.*

Introduction

Newcastle disease (ND) is an acute, highly contagious, and endemic viral disease of poultry worldwide (Abdisa & Tagesu, 2017; Suarez et al., 2020). Respiratory, gastrointestinal, and neurological manifestations are the main clinical pictures of ND infections. The disease is associated with significant global economic losses in the poultry industry, including high morbidity and mortality rates, immunosuppression, increasing the costs of vaccinations and control, and probable trade restrictions (Alexander, 2001; Ganar et al., 2014). The World Organization for Animal Health included ND in the list (A) of notifiable diseases (OIE, 2012). It has been reported that about 236 free-living avian species could be infected either naturally or experimentally with ND (Kaleta & Baldauf, 1988).

Avian paramyxoviruses have been divided into 12 different serotypes based on hemagglutination inhibition (HI) and neuraminidase inhibition assays (Dimitrov et al., 2016). Newcastle disease virus (NDV) belongs to avian paramyxovirus serotype 1 (APMV-1) in the family *Paramyxoviridae* and the genus *Avulavirus* (Cox & Plemper, 2017). The virus is a single-stranded, negative-sense, and non-segmented RNA genome that contains 6 genes in the sequence of 3′-NP-P-M-F-HN-L-5′ (Gogoi et al., 2017; Dimitrov et al., 2019). APMV-1 is circulating as an enzootic infection in many continents, such as Europe, Africa, Asia, and America (Miller et al., 2010). Infection with APMV-1 has shown variation in pathogenicity, from asymptomatic to lethal disease, due to the significant differences in strains virulence (Heiden et al., 2014). Three major pathotypes of NDV have been recognized in poultry based on the degree of the pathogenicity indices. They include the mean death time (MDT), intracerebral pathogenicity index (ICPI), and intravenous pathogenicity index (IVPI). Apathogenic NDV strains are non-virulent and show enterotropism, while lentogenic strains are of low virulence and produce mild respiratory manifestations (Alexander, 1997). Mesogenic strains of NDV are of moderate pathogenicity and infect mainly the respiratory tract, causing death in birds under 8 weeks of age (Beard & Hanson, 1984), while highly virulent velogenic strains (viscerotropic and neurotropic) induce systemic infections and a high mortality rate (Susta et al., 2011; Miller & Koch, 2013).

Pigeons could be divided into 3 categories: meat-type pigeons, homing pigeons, and fancy pigeons. Recently, the pigeon industry has shown rapid development, but the disease situation caused by viral affections is not helping and is not hopeful. Owing to the migratory nature of pigeons, difficulties in vaccinations, and their existence in live bird markets and backyard houses, they are regarded as a major threat for NDV transmission to domestic chickens. APMV-1 infects almost all avian species, including pigeons. Therefore, pigeons are regarded as a natural host of APMV-1 and play an important role in the

Corresponding to Wafaa A. Abd El-Ghany, Poultry Diseases Department, Faculty of Veterinary Medicine, Cairo University, 12211, Giza, Egypt E. mail: wafaa.soliman@cu.edu.eg

virus ecology (Pestka et al., 2014). ND in pigeons is called paramyxovirosis and is caused by an antigenic "pigeon variant" of the virus (pigeon paramyxovirus type 1, PPMV-1). PPMV-1 is an antigenic variant of APMV-1, which is mainly associated with infection of pigeons (Pestka et al., 2014). Since the genotype VI of NDV is frequently detected in pigeons, this strain is commonly named PPMV-1 (Alexander et al., 1985b; Tian et al., 2020; Xie et al., 2020). Genotypes VI, XX, and XXI of NDV are sometimes assigned as PPMV-1, which is regarded as the most genetically diverse group among the virus strains (Dimitrov et al., 2016). Despite the fact that PPMV-1 is responsible for severe disease conditions in domestic pigeons (Alexander, 2009), it occasionally spreads to a wide variety of other species, including feral pigeons, doves, and exotic birds (Alexander, 2000). Nowadays, PPMV-1 has been reported as an enzootic infection of feral, racing, and fancy pigeons (Alexander, 2011). Young pigeons are more susceptible to PPMV-1 and show neurological disorders with high morbidity and mortality rates (Chang et al., 2021; Badr et al., 2022). The central nervous system, respiratory system, alimentary tract, and kidney are usually affected by PPMV-1. Routine diagnosis of PPMV-1 is based on primary isolation in specific pathogen-free (SPF) embryonated chicken or pigeon eggs or on tissue culture (Gough et al., 1988), followed by a hemagglutination (HA) assay. Confirmation of infection should be carried out using conventional serological tests such as HI test or molecular-based techniques (OIE, 2021).

Infection of humans with APMV-1 is usually rare and may cause an asymptomatic condition or a mild disease, especially in immune-competent people (Capua & Alexander, 2004). The direct contact of humans with diseased pigeons may lead to conjunctivitis or, rarely, to flu-like symptoms (Zehetbauer et al., 1971; Schemera et al., 1987). In severe cases, infected people may show long-term vision damage (Beard & Hanson, 1984; Lamb & Parks, 2007). The disease usually shows self-limiting symptoms, which develop within 24 hours of exposure to PPMV-1 and resolve within a week (Swayne & King, 2003). Though the zoonotic potential of PPMV-1 is low, veterinary authorities urge people not to touch diseased or dead pigeons.

Despite vaccination, PPMV-1 is still enzootic in pigeons in some countries (Alexander, 2001). The gold standards for the prevention of PPMV-1 infection in pigeons are the administration of vaccines (Vindevogel & Duchatel, 1985; Zhao et al., 2010; Soliman et al., 2019), along with the adoption of effective biosecurity measures.

From the abovementioned, this review article was designed to focus on PPMV-1 infection in regards to the virus characteristics, epidemiology, diagnosis, human infection, and control.

The virus

According to the International Committee on Taxonomy of Viruses, *Orthoavulavirus* 1 (NDV) belongs to the order *Mononegavirales*, family *Paramyxoviridae*, subfamily *Avulavirinae*, and genus *Orthoavulaviruses* (ICTV, 2020). It is an enveloped virus with single-stranded RNA that is linear, pleomorphic (mostly spherical), non-segmented, and has a negative polarity (Amarasinghe et al., 2019). The genome of NDV is around 15–19 kilobases in length and encodes 6 structural proteins: nucleocapsid protein (NP), phosphoprotein (P), matrix (M) protein, fusion (F) protein, hemagglutinin-neuraminidase (HN), and RNA large polymerase (L) protein in the following order of 30-NP-P-M-F-HN-L-5 (Czegledi et al., 2006). Besides, the gene P encodes 2 additional non-structural (V and W) proteins by RNA editing (Steward et al., 1993; Karsunke et al., 2019). Both F and HN glycoprotein spike projections on the virus envelope are important for infection, fusion, and propagation of most paramyxoviruses in the host cell (Lamb & Parks, 2007). Moreover, the F protein is regarded as a key factor in NDV pathogenicity (Panda et al., 2004). Other internal proteins are involved in some functions, including transcription and replication of the virus (Dimitrov et al., 2016; Gogoi et al., 2017).

Although APMV-1 has a single serotype, the phylogenetic characterization of F gene sequences reveals the presence of 2 distinct classes (class I and class II) (Diel et al., 2012). Both classes are consequently subdivided into many different genotypes and clades. Class I of the virus consists of a single genotype, and it is mostly isolated from natural reservoirs of free-living wild and domestic waterfowl without pathogenicity to chickens (Kim et al., 2007; Chen et al., 2021; Lu et al., 2021). Class I virus strains are characterized by a 15,198-nt genomic RNA. On the other hand, class II can be separated into 21 genotypes (I to XXI, no XV) and represents the major cause of the disease outbreaks all over the world (Diel et al., 2012; Courtney et al., 2013; Dimitrov et al., 2019). Class II viruses show variable pathogenicity (both avirulent and virulent strains), as genotypes V, VI, VII, VIII, and XI–XVIII are the most pathogenic ones (Snoeck et al., 2013). Two new genotypes of XX and XXI and some strains of genotype VI have been designated as variant NDV strains, particularly in Columbiformes (Dimitrov et al., 2019). The strains of PPMV-1 are clustered into genotypes VI and XXI (Aldous et al., 2004). Genotype I–IV viruses are early lineage with a genome size of 15 186 nt, while genotype V–VIII viruses are recent lineage with a genome of 15 192 nt (Ujvari et al., 2006). Moreover, class II genotype VI is further divided into VIa–VIg. Moreover, Aldous et al. (2003) defined 6 lineages (class I viruses were lineage 6) with many sub-lineages. PPMV-1 viruses are placed in class II and lineage 4b or VIb, depending

on the used nomenclature. NDV has a specific amino acid sequence at the fusion protein gene cleavage site ["multiple basic amino acids (positions 113–116) at the C-terminus of the F2 protein and phenylalanine at position 117 at the end of the F1 protein"] (OIE, 2021). At the cleavage location of the F0 precursor, the most virulent strains of NDV has a sequence of "112R/K-R-Q-R/K-R*F117", in comparison with avirulent strains that have "112G/E-K/R-Q-G/E-R*L117", which is considered as a major determinant of the virus virulence (Collins et al., 1993). Therefore, the virulence of NDV strains could be determined through the F protein cleavage site amino acid sequence analysis (Le et al., 1988), as well as through the ability of separation of specific cellular proteases to cleave the F protein pathotypes (Ogasawara et al., 1992). The World Organization for Animal Health has defined virulent NDV as APMV-1 with at least 3 multiple basic amino acid residues (arginine or lysine) at the C-terminus of the F2 protein (between residues 113 and 116) and phenylalanine at residue 117, which is the N-terminus of the F1 protein (Alexander, 2008, 2011). It has been documented that lentogenic or avirulent NDV strains have fewer basic amino acids in the F protein cleavage site than either mesogenic or velogenic isolates, which have similar cleavage site sequences (Glickman et al., 1988).

Epidemiology

Distribution

Despite the fact that infections of pigeons with PPMV-1 have been detected since the 1930s (Doyle, 1933), the 3rd NDV panzootic started during the late 1970s (Yang et al., 1999) and is present in many countries until now. Around 1979, PPMV-1 was also reported in the Middle East (Kaleta et al., 1985a), and then the virus strains were detected in some European countries (Alexander et al., 1985a, b). In 1984, feedstuff was contaminated by feral pigeons in the docks in Liverpool, United Kingdom, resulting in 19 NDV outbreaks due to PPMV-1 in chickens (Alexander et al., 1985a). Moreover, outbreaks of PPMV-1 in commercial and backyard poultry have been reported in Brazil (Zanetti et al., 2001; Souza et al., 2018; Thomazelli et al., 2021; Pereira et al., 2022), Poland (Smietanka & Minta, 2011), Ireland (O'Reilly et al., 1994), Germany (Werner et al., 1999), Switzerland (Alexander et al., 1985b; Annaheim et al., 2022), Slovenia (Krapez et al., 2010), Macedonia (Dodovski et al., 2013, 2017), Japan (Mase & Kanehira, 2015), China (Liu et al., 2006; Wang et al., 2015; Qiu et al., 2017; Wei et al., 2018; He et al., 2020; Tian et al., 2020; Xie et al., 2020; Zhan et al., 2022), South Africa (Pienaar & Cilliers, 1987; Abolnik et al., 2004, 2008), Nigeria (Snoeck et al., 2013), Iran (Mayahi et al., 2017; Rezaei Far et al., 2017), and Egypt (Mohamed et al., 1980; Ahmed & Sabri, 1989; Shakal, 1989; Abou Hashem, 1993; Ibrahim et al., 2005; Soliman et al., 2016; Mansour et al., 2017).

Susceptibility

All ages of pigeons are susceptible to PPMV-1 infection with high morbidity and mortality rates (Kim et al., 2008; Qiu et al., 2017; Tian et al., 2020). Not only domestic pigeons are susceptible to PPMV-1, but also feral pigeons may carry the virus as asymptomatic carriers (Teske et al., 2013; Mase & Kanehira, 2015). Feral or wild pigeons have shed PPMV-1 during foraging in rural areas and posed a potential threat to the spread of the disease to free-range chickens (He et al., 2018). The PPMV-1 isolate that belongs to sub-genotype XXI.2 has been reported in collared doves in Italy (Bonfante et al., 2012) and in Eurasian collared doves in Iran (Esmaeelzadeh-Dizaji et al., 2022). PPMV-1 has also been isolated from wild North American doves (Kim et al., 2008). The study of Śmietanka et al. (2014) has shown that PPMV-1 strain was highly virulent to pigeons, followed by chickens and turkeys, but quails and geese showed the highest level of innate resistance to the used strain. Nevertheless, the passing of PPMV-1 in chickens has resulted in increased ICPI. There is no evidence of PPMV-1 infections in wild non-Columbiformes. However, the virus is occasionally isolated from migratory birds (Alexander et al., 2012).

Transmission

PPMV-1 could be excreted in the nasal, buccal, and ocular secretions and droppings of the infected pigeons. The virus is transmitted horizontally among birds either by inhalation or ingestion (Kaleta et al., 1992). Direct contact between healthy and diseased birds helps in the rapid spread of infection. The rapid transmission of PPMV-1 among Columbiforms may also be possible during competition flights (racing pigeons), exhibitions (show pigeons), live bird markets (meet pigeons), or intensive trade (Aldous et al., 2014; Sabra et al., 2017).

Clinical picture

The incubation period of PPMV-1 infection is 7–14 days. The clinical picture of infection varies according to the virulence of the infective strain, the immune status of the host, and the presence of other infections (Alexander & Senne, 2008). Pigeons show clinical signs similar to neurotropic NDV-infected chickens. Affected pigeons may display moderate to severe depression, circling, ataxia, torticollis, head and neck tremors and twisting, leg and wing paralysis, greenish diarrhea, and respiratory manifestations (Vindevogel & Marlier, 2006; Wang et al., 2015; Badr et al., 2022). Viscerotropic strains of PPMV-1 exhibit specific affinity for the kidneys; thus, the first observed sign is polyuria, and neural symptoms appear only in individual birds (Pestka et al., 2014). However, an asymptomatic course of infection may occur (Alexander et al., 1984a). Infection with PPMV-1 may cause a mortality rate that ranges from 10% to

70%, as does the morbidity, which ranges from 30% to 80% in the infected pigeons (Hutchison, 1984; Mansour et al., 2017; Qiu et al., 2017). Concurrent infections with other bacterial or parasitic infections increase the mortality rate. Survived pigeons may shed the virus and, therefore, represent a source of infection (Alexander et al., 1984b). The post-mortem lesions of dead pigeons with PPMV-1 have revealed soft or friable tissues of the brain and/or hemorrhages, severe hemorrhagic enteritis, petechial hemorrhage in the gizzard, and congested liver (Dodovski et al., 2017; Badr et al., 2022). It has been documented that PPMV-1 in chickens is of intermediate virulence (a mesogenic virus) (Collins et al., 1994; Hüppi et al., 2020), and the infection may vary from subclinical to a marked drop in egg production (Guo et al., 2014). Though PPMV-1 strains sometimes cause mild disease, multiple passages in chickens may result in increasing virus virulence in the form of signs, mortality, and neuro-invasiveness (Kommers et al., 2001, 2003; Dortmans et al., 2011). Moreover, many NDV outbreaks in chickens have been attributed to PPMV-1 infection (Alexander et al., 1984b; Werner et al., 1999). Several point mutations are sufficient to increase the pathogenicity of PPMV-1 in chickens (Meulemans et al., 2002; Dortmans et al., 2009). The histopathological examination of the examined brains of PPMV-1-infected pigeons has revealed the presence of non-suppurative encephalitis, necrosis, and microgliosis (Wakamatsu et al., 2006; Pereira et al., 2022). Diffuse inflammation of the respiratory and intestinal tract tissues has also been detected (Aldous & Alexander, 2001).

Human infection

Infection of humans with APMV-1 is rarely detected, and it is not considered a life-threatening condition so far. However, sporadic infections have been reported in patients with occupational exposure to commercially infected poultry flocks (Capua & Alexander, 2004). Most of the APMV-1 human cases have occurred through direct contact with infected birds; mostly, workers in poultry farms, laboratories, and processing plants are at a high risk of getting infections. The clinical signs are usually transitory mild conjunctivitis, and most of the patients resolve without medical or clinical interference (Steele & Beran, 1981). Frequent symptoms of eye disorders (Lippmann, 1952; Capua & Alexander, 2004), unilateral or bilateral eye redness, eyelid edema, conjunctivitis, sub-conjunctival hemorrhage, and acute keratoconjunctivitis have been reported in a case with concurrent NDV and human adenovirus infection (Prajna et al., 2021). Nevertheless, lethal pneumonic studies of APMV-1 have been found in immune-compromised persons following blood stem cell/allogeneic bone marrow transplantations (Goebel et al., 2007; Kuiken et al., 2018). Another child case caused by APMV-1 has shown fatal encephalitis after hematopoietic stem-cell transplantation (Winter et al., 2021). The strain of APMV-1 isolated from a pneumonic patient was also of pigeon origin (Goebel et al., 2007). Kuiken et al. (2017) have found that PPMV-1 from a fatal human case induced pneumonia in experimentally infected Cynomolgus macaques. Moreover, APMV-1-associated pneumonia and death have been detected in a 64-year-old person following contact with a live pigeon (Abbo et al., 2007). Following extensive laboratory investigation of the previous case, both APMV-1 and *Acinetobacter baumannii* (ABA) have been detected. Recently, a similar case was reported in 2020 in China, where a 64-year-old man presented with severe acute respiratory distress syndrome and sepsis, followed by death within a few days (Zou et al., 2022). The patient had close contact with pigeons before illness, and PPMV antibodies were detected in his blood within 20 days of illness. Besides, the metagenomic sequencing revealed the presence of ABA and APMV-1 genotype VI.2.1.1.2.2 in the broncho-alveolar lavage fluid, and the virus nucleic acid was found in the pigeon feathers. This study emphasizes the cross-species transmission of PPMV-1 between infected pigeons and humans.

Diagnosis and differential diagnosis

The primary isolation of PPMV-1 could be achieved via inoculation of SPF embryonated chicken or pigeons eggs. The embryos die between the 2nd and 8th day of inoculation and show curling and sometimes dwarfing with head and body hemorrhages as well as presence of urates even mixed with allantoic fluids. The HA of allantoic fluid may confirm the presence of PPMV-1. Tissue culture, including chicken embryo fibroblasts, chicken primary neuronal cells, pigeon embryo fibroblasts, and pigeon primary neuronal cells have been used for primary isolation of PPMV-1 (Guo et al., 2018; Zhan et al., 2020). Serological tests, particularly the HI assay, have been used for detection of antibodies in the serum of PPMV-1 infected pigeons (Ibrahim et al., 2005).

The pathogenicity of the virus could be determined by assessing the MDT in 10-day-old SPF embryonated chicken or pigeon eggs and the ICPI in 1-day-old SPF chicks based on standard procedures (OIE, 2012). Virulent NDV strains are those with MDT less than 60 hours and ICPI values of 0.7 or more (defined as the mean observed score per bird as 0 if normal, 1 if diseased, or 2 if dead over the 8-day period) (Dortmans et al., 2009, 2010). The IVPI of PPMV-1 could be determined after inoculation of freshly infective allantoic fluids into a 6-week-old pigeon, as each bird should be examined daily for a period of 10 days and scored for assessment of the virus virulence (mesogenic, velogenic, etc.).

The molecular identification of PPMV-1 has been comprehensively carried out using polymerase chain

reaction (Aldous et al., 2004, 2014; Wei et al., 2018; Esmaeelzadeh-Dizaji et al., 2022). Virulent PPMV-1 strains have a specific amino acid sequence at the F protein gene cleavage site (amino acids positions 113–116 at the C-terminus of the F2 protein and phenylalanine at position 117 at the end of the F1 protein) (Dimitrov et al., 2017; OIE, 2021).

Signs of PPMV-1 in pigeons are similar to pigeon herpes virus infection, sodium chloride poisoning, and overdose of ronidazole or vitamin B1 deficiency. Therefore, laboratory tests are essential for an accurate diagnosis (Hamouda et al., 2017).

Control

There is no specific treatment for PPMV-1 infection because infected birds usually die within 72 hours; however, some recovered birds may survive with supportive treatment. Control of PMV-1 infection can be achieved via the adoption of strict biosecurity measures and a proper vaccination regimen (Miller & Koch, 2013). Vaccination of pigeons could reduce the losses and the hazards of the spread of infection to other pigeons and/or other bird species. Pigeons could be protected against infection using chicken NDV-live or -inactivated oil-emulsion vaccines (Viaene et al., 1984). Ibrahim et al. (2005) have found a close immunogenic relationship among PPMV-1 and NDV vaccine strains, which may answer the question of why we use NDV vaccines for controlling PPMV-1 infection in pigeons. Immunization of commercial or racing pigeons with inactivated APMV-1 vaccines is also important (Alexander et al., 1985b). Lentogenic strains of NDV showed some virulence for pigeons and might be excreted 3–7 days post inoculation; thus, inactivated vaccines are preferred for racing pigeons (Vindevogel et al., 1982). Viaene et al. (1983, 1984) reported that LaSota and oil-inactivated NDV vaccines provided protection for pigeons against PMV-1 infection for up to 6 months. However, it has been reported that the Hitchner B1 live NDV vaccine could not protect pigeons against the virus as it could not propagate in pigeon tissues and thus could not induce suitable immunity (Kaleta et al., 1985b). Alexander et al. (1986) demonstrated that vaccination of pigeons against PPMV-1 was not analogous to vaccination against NDV in chickens due to the differences in the hosts or the antigenic variations between pigeons and classical PPMV-1 strains, including the vaccinal viruses.

Homologous vaccine is necessary for a complete protection of pigeons against the disease (Fritzsch et al., 1984; Eskelund, 1986; Stone, 1989; Amer, 2008). Vaccinated pigeons with a homologous oil emulsion vaccine against PPMV-1 infection were more highly protected than pigeons vaccinated with commercial live NDV vaccines for a year (Alexander and Parsons, 1984; Amer et al., 2013). Inactivated NDV vaccines provoked a relatively high antibody titer, which was sufficient to protect pigeons against PPMV-1, while the Hitchner B1 live vaccine did not (Polten et al., 1985; Kosters et al., 1986). Duchatel and Vindevogel (1986) found that inoculation of 0.2 mL of inactivated aqueous-suspension vaccines prepared from the LaSota strain of NDV gave a high resistance to a severe challenge with PPMV-1. Box et al. (1985) suggested using double doses of an inactivated oil-emulsion vaccine 4 weeks apart to provide a good protection for pigeons. Inactivated vaccines from the local PPMV-1 strain were developed, and the results revealed a protection rate of 80% with a high level of immune response that lasted for 5 months (El-Zanaty et al., 1992; Hassan, 1997). Wawizkiewicz et al. (1991) demonstrated that the oil emulsion PPMV-1 vaccine gave a higher HI antibody response on the 3rd week after the 2nd vaccination dose. Besides, Amer et al. (2013) have reported that the PPMV-1 vaccine gave 100% protection for vaccinated pigeons against the homologous virus compared with only 10% protection in non-vaccinated birds. A combined inactivated vaccine containing oil adjuvanted local strains of PPMV-1 and *Salmonella typhimurium* is safe, potent, and provides a full protection in terms of increasing the HI antibody titers and reducing mortality post-challenge (Khedr et al., 2016). These findings suggest that sub-strains may exist in the PPMV-1, which necessitates the continuous update of the vaccine master seeds with new field isolates to maintain high protection level (Soliman et al., 2019). Subcutaneous inoculation of pigeons with an aluminum hydroxyl-based formula of the PPMV-1 YA/14 vaccine provides a higher humoral immune response with a lower shedding level than the oil-based vaccine (Soliman et al., 2019).

Conclusion

PPMV-1 infection is widespread; therefore, prevention of the pigeon's infection looks significant and needs thorough investigation. Besides, the mechanisms by which APMV-1 causes severe human infection should be more thoroughly explored. Pigeons may not show clear signs of PPMV-1 infection or deaths, but they can catch the virus and induce specific antibodies. Despite vaccination, PPMV-1 is still enzootic in pigeons in certain countries. Vaccination of pigeons with the NDV vaccine or a specific PPMV-1 vaccine gains attention to avoid the virus shedding to other birds. The use of a homologous vaccine is the most suitable solution for the control of such infection. Personnel should wear protective clothes and equipment when handling and processing potentially infected poultry. The surveillance studies of PPM-1 are necessary to prepare health authorities better.

Conflict of Interests

The author declare that there is no conflict of interests.

References

1. Abbo A., Carmeli Y., Navon-Venezia S., Siegman-Igra Y., Schwaber M. J. Impact of multi-drug-resistant *acinetobacter baumannii* on clinical outcomes. European Journal of Clinical Microbiology & Infectious Diseases. 2007. T. 26(11). P. 793-800. https://doi.org/10.1007/s10096-007-0371-8
2. Abdisa T., Tagesu T. Review on Newcastle disease of poultry and its public health importance. Journal of Veterinary Science and Technology. 2017. T. 8(3). P. 441. https://doi.org/10.4172/2157-7579.1000441
3. Abolnik C., Horner R. F., Maharaj R., Viljoen, G. J. Characterization of a pigeon paramyxovirus (PPMV-1) isolated from chickens in South Africa. Onderstepoort Journal of Veterinary Research. 2004. T. 71(2). P. 157-160. https://doi.org/10.4102/ojvr.v71i2.278
4. Abolnik C., Gerdes G. H., Kitching J., Swanepoel S., Romito M., Bisschop S. P. R. Characterization of pigeon paramyxoviruses (Newcastle disease virus) isolated in South Africa from 2001 to 2006. Onderstepoort Journal of Veterinary Research. 2008. T. 75(2). P. 147-152. https://doi.org/10.4102/ojvr.v75i2.13
5. Abou Hashem N. A. Studies on some paramyxovirus infections in pigeons. MVSc thesis, Department of Poultry and Fish Diseases, Faculty of Veterinary Medicine, Zagazig University, Egypt. 1993.
6. Ahmed H. N., Sabri I. Isolation of Newcastle disease virus from pigeons infected with pigeon pox. Journal of Veterinary Science UAR. 1989. T. 6. P. 47-53.
7. Aldous E. W., Alexander D. J. Detection and differentiation of Newcastle disease virus (avian paramyxovirus type 1). Avian Pathology. 2001. T. 30(2). P. 117-128. https://doi.org/10.1080/03079450120044515
8. Aldous E. W., Mynn J. K., Banks J., Alexander D. J. A molecular epidemiological study of avian paramyxovirus type 1 (Newcastle disease virus) isolates by phylogenetic analysis of a partial nucleotide sequence of the fusion protein gene. Avian Pathology. 2003. T. 32(3). P. 239-357. https://doi.org/10.1080/0307945031000097 83
9. Aldous E. W., Fuller C. M., Mynn J. K., Alexander D. J. A molecular epidemiological investigation of isolates of the variant avian paramyxovirus type 1 virus (PPMV-1) responsible for the 1978 to present panzootic in pigeons. Avian Pathology. 2004. T 33(2). P. 258-269. https://doi.org/10.1080/0307945042000195768
10. Aldous E. W., Fuller C. M., Ridgeon J. H., Irvine R. M., Alexander D. J., Brown I. H. The evolution of pigeon paramyxovirus type 1 (PPMV-1) in Great Britain: A molecular epidemiological study. Transboundary and Emerging Diseases. 2014. T. 61(2). P. 134-139. https://doi.org/10.1111/tbed.12006
11. Alexander D. J. Newcastle Disease and other paramyxoviruses infection, in diseases of Poultry. Edited by: Calnek B. W., Barnes H. J., Beard C. W., McDoughal L. R., Saif Y. M., Ames L. A. 1997.
12. Alexander D. J. Newcastle disease and other avian paramyxoviruses. Revue Scientifique et Technique. 2000. T. 19(2). P. 443-462. http://dx. doi.org/10.20506/rst.19.2.1231
13. Alexander D. J. Newcastle disease. British Poultry Science. 2001. T. 42(1). P. 5-22. https://doi.org/10.1080/713655022
14. Alexander D. J. Newcastle disease. In: World Organisation for Animal Health (OIE) Manual of Diagnostic Tests and Vaccines for Terrestrial Animals. 6th ed. Paris: OIE. 2008. 576-589p.
15. Alexander D. J. Ecology and epidemiology of Newcastle disease. In: Capua, I., Alexander, D. J., editors. Avian Influenza and Newcastle Disease: A Field and Laboratory Manual. Milano: Springer Milan. 2009. 19-26p. https://doi.org/10.1007/978-88-470-0826-7_2
16. Alexander D. J. Newcastle disease in the European Union 2000 to 2009. Avian Pathology. 2011. T. 40(6). P. 547-558. https://doi.org/10.1080/03079457.2011.618823
17. Alexander D. J., Parsons G. Avian paramyxoviruses type-1 infections of racing pigeons: 2 Pathogenicity experiments in pigeons and chickens. Veterinary Record. 1984. T. 114(19). P. 466-469. https://doi.org/10.1136/vr.114.19.466
18. Alexander D. J., Senne D. A. Newcastle disease and other avian paramyxoviruses. In: Dufour-Zavala, L., ed, A Laboratory Manual for the Isolation Identification and Characterization of Avian Pathogens. 4th ed. Athens, GA: AAAP; 2008. 135-141p.
19. Alexander D. J., Wilson G. W., Thain J. A., Lister S. A. Avian paramyxovirus type 1 infection of racing pigeons: 3 epizootiological considerations. Veterinary Record. 1984a. T. 115(9). P. 213-216. https://doi.org/10.1136/vr.115.9.213
20. Alexander D. J., Parsons G., Marshall R. Infection of fowls with Newcastle disease virus by food contaminated with pigeon faeces. Veterinary Record. 1984b. T. 115(23). P. 601-602. https://doi.org/10.1136/vr.115.23.601
21. Alexander D. J., Wilson G. W., Russell P. H., Lister S. A., Parsons, G. Newcastle disease outbreaks in fowl in Great Britain during 1984. Veterinary Record. 1985a. T. 117(17). P. 429-434. https://doi.org/10.1136/vr.117.17.429
22. Alexander D. J., Russell P. H., Parsons G., Elzein E. M., Ballouh A., Cernik K., Engstrom B., Fevereiro M., Fleury H. J., Guittet M., Kaleta E. F., Kihm U., Kosters J., Lomniczi B., Meister J., Meulemans G., Nerome K., Petek M., Pokomunski S., Polten B., Prip M., Richter R., Saghy E., Samberg Y., Spanoghe L., Tumova B. Antigenic and biological characterisation of avian paramyxovirus type I isolates from pigeons-an international collaborative study. Avian Pathology. 1985b. T. 14(3). T. 365-376. https://doi.org/10.1080/03079458508436238
23. Alexander D. J., Parsons G., Marshall R. Avian paramyxovirus type 1 infections of racing pigeons: 4. Laboratory assessment of vaccination. Veterinary Record. 1986. T. 118(10). P. 262-266. https://doi.org/10.1136/vr.118.10.262
24. Alexander D. J., Aldous E. W., Fuller C. M. The long view: A selective review of 40 years of Newcastle disease research. Avian Pathology. 2012. T. 41(4). P. 329-335. https://doi.org/10.1080/03079457.2012.697991
25. Amarasinghe G. K., Ayllon M. A., Bao Y., Basler C. F., Bavari S., Blasdell K. R., Briese T., Brown P. A., Bukreyev A., Balkema Buschmann A., Buchholz U. J., Chabi-Jesus C., Chandran K., Chiapponi C., Crozier I., de Swart R. L., Dietzgen R. G., Dolnik O., Drexler J. F., Dürrwald R., Dundon W. G., Duprex W. P., Dye J. M., Easton A. J., Fooks A. R., Formenty P. B. H., Fouchier R. A. M., Freitas-Astúa J., Griffiths A., Hewson R., Horie M., Hyndman T. H., Jiāng D., Kitajima E. W., Kobinger G. P., Kondō H., Kurath G., Kuzmin I. V., Lamb R. A., Lavazza A., Lee B., Lelli D., Leroy E. M., Lǐ J., Maes P., Marzano S. L., Moreno A., Mühlberger E., Netesov S. V., Nowotny N., Nylund A., Økland A. L., Palacios G., Pályi B., Pawęska J. T., Payne S. L., Prosperi A., Ramos-González P. L., Rima B. K., Rota P., Rubbenstroth D., Shī M., Simmonds P., Smither S. J., Sozzi E., Spann K., Stenglein M. D., Stone D. M., Takada A., Tesh R. B., Tomonaga K., Tordo N., Towner J. S., van den Hoogen B., Vasilakis N., Wahl V., Walker P. J., Wang L. F., Whitfield A. E., Williams J. V., Zerbini F. M., Zhāng T., Zhang Y. Z., Kuhn J. H. Taxonomy of the order Mononegavirales: Update 2019. Archive of Virology. 2019. T. 164(7). P. 1967-1980. https://doi.org/10.1007/s00705-019-04247-4
26. Amer M. I. S. Trial for Preparation of an Inactivated Pigeon Paramyxo Virus Vaccine. M.V.Sc. Thesis, Dept. of Virology, Fac. Vet. Med., Banha University, 2008.
27. Amer M. I. S., El-Bagoury G. F., Khodeir M. H. Evaluation of the immune response of pigeons to Newcastle disease and pigeon paramyxo virus vaccines. Benha Veterinary Medical Journal. 2013. T. 24(2). P. 148-156.
28. Annaheim D., Vogler B. R., Sigrist B., Vögtlin A., Hüssy D., Breitler C., Hartnack S., Grund C., King J., Wolfrum N., Albini S. Screening of healthy feral pigeons (*Columba livia domestica*) in the city of Zurich reveals continuous circulation of pigeon paramyxovirus-1 and a serious threat of transmission to domestic poultry. Microorganisms. 2022. T. 10(8). P. 1656. https://doi.org/10.3390/microorganisms10081656
29. Badr H, Shosha E. A., Roshdy H., Mohammed A. A., Saad N., Aboelenin S. M., Soliman M. M., El-Tahan A. M., El-Saadony M. T., Yehia N. Investigation of many bacterial and viral infections circulating in pigeons showing nervous symptoms.

Saudi Journal of Biological Sciences. 2022. T. 29(4). P. 2911-2920. https://doi.org/10.1016/j.sjbs.2022.01.023.
30. Beard C. W., Hanson R. P. In: Diseases of Poultry, 8th edition (Eds. Hofstad, M. S., Barnes, H. J., Calnek, B. W., Reid W. M., Yoder, H.W.), Iowa State University Press, Ames, 1984. 452-470p.
31. Bonfante F., Terregino C., Heidari A., Monne I., Salviato A., Taddei R., Raffini E., Capua I. Identification of APMV-1 associated with high mortality of collared doves (*Streptoelia decaocto*) in Italy. Veterinary Record. 2012. T. 171(13). P. 327. https://doi.org/10.1136/vr.100448
32. Box P. G., Holmes H. C., McCartney E. Vaccination of pigeons against paramyxovirus type 1 infection. Veterinary Record. 1985. T. 117. P. 555-556.
33. Capua I., Alexander D. J. Human health implications of avian influenza viruses and paramyxoviruses. European Journal of Clinical Microbiology & Infectious Diseases. 2004. T. 23(1). P. 1-6. https://doi.org/10.1007/s10096-003-1059-3
34. Chang H., Feng S., Wang Y., Li F., Su Q., Wang B., Du J., He H. Isolation and pathogenic characterization of pigeon paramyxovirus type 1 via different inoculation routes in pigeons. Frontiers in Veterinary Science. 2021. T. 7. P. 569901. https://doi.org/10.3389/fvets.2020.569901
35. Chen L., Song J., Liu H., Cai J., Lin Q., Xu C., Ding C., Liao M., Ren T., Xiang B. Phylodynamic analyses of class I Newcastle disease virus isolated in China. Transboundary and Emerging Diseases. 2021. T. 68(3). P. 1294-1304. https://doi.org/10.1111/tbed.13785
36. Collins M. S., Bashiruddin J. B., Alexander D. J. Deduced amino acid sequences at the fusion protein cleavage site of Newcastle disease viruses showing variation in antigenicity and pathogenicity. Archives of Virology. 1993. T. 128(3-4). P. 363-370. https://doi.org/10.1007/bf01309446
37. Collins M. S., Strong I., Alexander D. J. Evaluation of the molecular basis of pathogenicity of the variant Newcastle disease viruses termed "pigeon PMV-1 viruses. Archives of Virology. 1994. T. 134(3-4). P. 403-411. https://doi.org/10.1007/bf01310577
38. Cox R. M., Plemper R. K. Structure and organization of paramyxovirus particles. Current Opinion in Virology. 2017. P. 24. T. 105-114. https://doi.org/10.1016/j.coviro.2017.05.004
39. Courtney S. C., Susta L., Gomez D., Hines N. L., Pedersen J. C., Brown C. C., Miller P. J., Afonso C. L. Highly divergent virulent isolates of Newcastle disease virus from the Dominican Republic are members of a new genotype that may have evolved unnoticed for over 2 decades. Journal of Clinical Microbiology. 2013. T. 51(2). P. 508-517. https://doi.org/10.1128/jcm.02393-12
40. Czegledi A., Ujvari D., Somogyi E., Wehmann E., Werner O., Lomniczi B. Third genome size category of avian paramyxovirus serotype 1 (Newcastle disease virus) and evolutionary implications. Virus Research. 2006. T. 120(1-2). P. 36-48. https://doi.org/10.1016/j.virusres.2005.11.009
41. Diel D. G., da Silva L. H., Liu H., Wang Z., Miller P. J., Afonso C. L. Genetic diversity of avian paramyxovirus type 1: proposal for a unified nomenclature and classification system of Newcastle disease virus genotypes. Infection, Genetics, and Evolution. 2012. T. 12(8). P. 1770-1779. https://doi.org/10.1016/j.meegid.2012.07.012
42. Dimitrov K. M., Ramey A. M., Qiu X., Bahl J., Afonso C. L. Temporal, geographic, and host distribution of avian paramyxovirus 1 (Newcastle disease virus). Infection, Genetics and Evolution. 2016. T. 39. P. 22-34. https://doi.org/10.1016/j.meegid.2016.01.008
43. Dimitrov K. M., Afonso C. L., Yu Q., Miller P. J. Newcastle disease vaccines-A solved problem or a continuous challenge? Veterinary Microbiology. 2017. T. 206. P. 126-136. https://doi.org/10.1016/j.vetmic.2016.12.019
44. Dimitrov K. M., Abolnik C., Afonso C. L., Albina E., Bahl J., Berg M., Briand F. X., Brown I. H., Choi K. S., Chvala I., Diel D. G., Durr P. A., Ferreira H. L., Fusaro A., Gil P., Goujgoulova G. V., Grund C., Hicks J. T., Joannis T. M., Torchetti M. K., Kolosov S., Lambrecht B., Lewis N. S., Liu H., Liu H., McCullough S., Miller P. J., Monne I., Muller C. P., Munir M., Reischak D., Sabra M., Samal S. K., Servan de Almeida R., Shittu I., Snoeck C. J., Suarez D. L., Van Borm S., Wang Z., Wong F. Y. K. Updated unified phylogenetic classification system and revised nomenclature for Newcastle disease virus. Infection, Genetic, and Evolution. 2019. T. 74. P. 103917. https://doi.org/10.1016/j.meegid.2019.103917
45. Dodovski A., Krstevski K., Ivancho N. Classical and molecular characterization of pigeon paramyxovirus type 1 (PPMV-1) isolated from backyard poultry–first report in Macedonia. Macedonian Veterinary Review. 2013. T. 36. P. 33-39.
46. Dodovski I., Cvetkovikj K., Krstevski I., Naletoski M., Vladimir S. Characterization and epidemiology of pigeon paramyxovirus type-1 viruses (PPMV-1) isolated in Macedonia. Avian Diseases. 2017. T. 61(2). P. 146-152. https://doi.org/10.1637/11517-101816-reg.1
47. Dortmans J. C., Koch G., Rottier P. J., Peeters B. P. Virulence of pigeon paramyxovirus type 1 does not always correlate with the cleavability of its fusion protein. Journal of General Virology. 2009. T. 90(Pt 11). P. 2746-2750. https://doi.org/10.1099/vir.0.014118-0
48. Dortmans J. C., Fuller C. M., Aldous E. W., Rottier P. J., Peeters B. P. Two genetically closely related pigeon paramyxovirus type 1 (PPMV-1) variants with identical velogenic fusion protein cleavage sites but with strongly contrasting virulence. Veterinary Microbiology. 2010. T. 143(2-3). P. 139-144. https://doi.org/10.1016/j.vetmic.2009.11.021
49. Dortmans J. C., Rottier P. J., Koch G., Peeters B. P. Passaging of a Newcastle disease virus pigeon variant in chickens results in selection of viruses with mutations in the polymerase complex enhancing virus replication and virulence. Journal of General Virology. 2011. T. 92(Pt 2). P. 336-345. https://doi.org/10.1099/vir.0.026344-0
50. Doyle T. The virus diseases of animals with special reference to those of poultry. Journal of Comparative Pathology and Therapeutics. 1933. T. 46. P. 90-107. https://doi.org/10.1016/S0368-1742(33)80014-2
51. Duchatel J. P., Vindevogel H. Assessment of vaccination of pigeons against paramyxovirus type 1 infection with inactivated aqueous-suspension or oil-emulsion vaccines. Avian Pathology. 1986. T. 15(3). P. 455-465. https://doi.org/10.1080/03079458608436307
52. El-Zanaty K., Abd El-Motilib T. Y., Seifedin M., Solem B. Vaccination against paramyxovirus type - 1. Assiut Veterinary Medical Journal. 1992. T. 26(52). P. 265-271.
53. Eskelund K. H. The control of paramyxovirus type-1 (PMV-1) infection in domestic pigeons. Proc. 35th Western Poultry Disease Conference, Puerto Vallarta, Jalisco, Mexico, 1986. T. 5. 51-53p.
54. Esmaeelzadeh-Dizaji R., Molouki A., Hosseini H., Fallah-Mehrabadi M. H., Ziafati-Kafi Z., Takalou A., Eram N., Kumar N., Ashuri A., Sadri N., Ghalyanchi-Langeroudi A. Molecular characterization of a pigeon paramyxovirus type 1 virus isolated from Eurasian collared doves in Iran, 2017. Journal of Veterinary Science. 2022. T. 23(3). P. e29. https://doi.org/10.4142/jvs.21254
55. Fritzsch K., Kabeta E. F., Ruger R., Meister J. Simultaneous vaccination of carrier pigeons against paramyxovirus-1 infection and pigeon pox. Praktische Tierarzt. 1984. T. 65(8). P. 676-678.
56. Ganar K., Das M., Sinha S., Kumar S. Newcastle disease virus: current status and our understanding. Virus Research. 2014. T. 184. P. 71-81 https://doi.org/10.1016/j.virusres.2014.02.016
57. Glickman R. L., Syddall R. J., Iorio R. M., Sheehan J. P., Bratt M. A. Quantitative basic residue requirements in the cleavage activation site of the fusion glycoprotein as a determinant of virulence for Newcastle disease virus. Journal of Virology. 1988. T. 62(1). P. 354-356. https://doi.org/10.1128/jvi.62.1.354-356.1988
58. Goebel S. J., Taylor J., Barr B. C., Kiehn T. E., Castro-Malaspina H. R., Hedvat C. V., Rush-Wilson K. A., Kelly C. D., Davis S. W., Samsonoff W. A., Hurst, K. R., Behr M. J., Masters P. S. Isolation of avian paramyxovirus 1 from a patient with a lethal case of pneumonia. Journal of Virology. 2007. T. 81(22). P. 12709-12714. https://doi.org/10.1128/jvi.01406-07

59. Gogoi P., Ganar K., Kumar S. Avian paramyxovirus: a brief review. Transboundary and Emerging Diseases. 2017. P. 64(1). T. 53-67. https://doi.org/10.1111/tbed.12355
60. Gough R. E., Alexander D. J., Collins M. S., Lister S. A., Cox W. J. Routine virus isolation or detection in the diagnosis of diseases in birds. Avian Pathology. 1988. T. 17(4). P. 893-907. https://doi.org/10.1080/03079458808436511
61. Guo H., Liu X., Xu Y., Han Z., Shao Y., Kong X., Liu S. A comparative study of pigeons and chickens experimentally infected with PPMV-1 to determine antigenic relationships between PPMV-1 and NDV strains. Veterinary Microbiology. 2014. T. 168(1). P. 88-97. https://doi.org/10.1016/j.vetmic.2013.11.002
62. Guo Y., Zhao J., Chang X., Yao W., Wang H., Wang W., Wang X., Zhang S., Yang Z., Xiao S. α2,3- and α2,6-linked sialic acids are important for cell binding and replication of Newcastle disease virus in chicken primary neuronal cells. Acta Virologica. 2018. T. 62(3). P. 235-245. https://doi.org/10.4149/av_2018_217
63. Hamouda E. E., Mohamed N. A. A., Eid A. A. M., Ismail A. N. A., El-Sisi M. A., Hassanin O. A. A., Abou-Hashem N. A. Utilization of RT-PCR and restriction enzyme analysis in detection and differentiation of pigeon paramyxovirus-1 and Newcastle disease virus in pigeons. Zagazig Veterinary Journal. 2017. T. 45(1). P. 37-47. https://doi.org/10.21608/zvjz.2017.29239
64. Hassan E. A. Some trials for vaccine production against paramyxovirus infection in pigeons. MVSc thesis, Virology, Faculty of Veterinary Medicine, Alexandria University, Egypt. 1997.
65. He Y., Taylor T. L., Dimitrov K. M., Butt S. L., Stanton J. B., Goraichuk I. V., Fenton H., Poulson R., Zhang J., Brown C. C., Ip H. S., Isidoro-Ayza M., Afonso C. L. Whole-genome sequencing of genotype VI Newcastle disease viruses from formalin-fixed paraffin-embedded tissues from wild pigeons reveals continuous evolution and previously unrecognized genetic diversity in the US. Virology Journal. 2018. T. 15(1). P. 9. https://doi.org/10.1186/s12985-017-0914-2
66. He Y., Lu B., Dimitrov K. M., Liang J., Chen Z., Zhao W., Qin Y., Duan Q., Zhou Y., Liu L., Li B., Yu L., Duan Z., Liu Q. Complete genome sequencing, molecular epidemiological, and pathogenicity analysis of pigeon paramyxoviruses type 1 isolated in Guangxi, China during 2012-2018. Viruses. 2020. T. 12(4). P. 366. https://doi.org/10.3390%2Fv12040366
67. Heiden S., Grund C., Höper D., Mettenleiter T. C., Römer-Oberdörfer A. Pigeon paramyxovirus type 1 variants with polybasic F protein cleavage site but strikingly different pathogenicity. Virus Genes. 2014. T. 49(3). P. 502-506. https://doi.org/10.1007/s11262-014-1111-7
68. Hüppi L., Ruggli N., Python S., Hoop R., Albini S., Grund C., Vögtlin A. Experimental pigeon paramyxovirus-1 infection in chicken: Evaluation of infectivity, clinical and pathological manifestations and diagnostic methods. Journal of General Virology. 2020. T. 101(2). P. 156-167. https://doi.org/10.1099/jgv.0.001364
69. Hutchison D. C. Paramyxovirus infection in pigeons. Veterinary Record. 1984. T. 115. P. 335.
70. Ibrahim R. S., Abdel-Motelib T. Y., Abdel-Hafez M. S. Paramyxovirus infection in pigeons. Assiut Veterinary Medical Journal. 2005. T. 51(104). P. 1-12. https://doi.org/10.21608/avmj.2005.177776
71. ICTV, International Committee on Taxonomy of Viruses. Virus Taxonomy 2020. Online meeting, October 2020. Available online at: https://talk. ictvonline.org/ taxonomy/
72. Kaleta E. F., Alexander D. J., Russell P. H. The first isolation of the avian PMV-1 virus responsible for the current panzootic in pigeons? Avian Pathology. 1985a. T. 14(4). P. 553-557. https://doi.org/10.1080/ 03079458508436258
73. Kaleta E.F., Polten B. M., Schmer N., Meister J. A. Immunization of pigeons against paramyxovirus – 1 infection with live adsorbed or inactivated emulsion vaccines. Praktische Tierarzt. 1985b. T. 66(10). P. 800-806.
74. Kaleta E. F., Baldauf C. Newcastle disease in free-living and pet birds. In Newcastle Disease; Alexander, D. J., Ed.; Springer: Boston, MA, USA, 1988; pp. 197–246, ISBN 978-1-4612-8987-6.
75. Kaleta E. F. Paramyxovirusinfektionen. In Krankheiten des Wirtschaftsgeflügels; Heider, G., Monreal, G., Eds.; Gustav Fischer Verlag Jena: Stuttgart, Germany, 1992. Band 1; 587-661p. ISBN 3-334-60348-2.
76. Karsunke J., Heiden S., Murr M., Karger A., Franzke K., Mettenleiter T. C., Römer-Oberdörfer A. W. protein expression by Newcastle disease virus. Virus Research. 2019. T. 263. P. 207-216. https://doi.org/10.1016/j.virusres.2019.02.003
77. Khedr A. A., Abdel Latef A. A., Sayed M. L., Abdrabo M. A., Nagy N., Radwan A. A., Abo Dalal S. E. Efficacy of an experimental combined inactivated *Salmonella typhimurium* and paramyxovirus vaccine in pigeons. Zagazig Veterinary Journal. 2016. T. 44(2). P. 149-155. https://doi.org/10.21608/zvjz.2016.7857
78. Kim L. M., King D. J., Curry P. E., Suarez D. L., Swayne D. E., Stallknecht D. E., Slemons R. D., Pedersen J. C., Senne D. A., Winker K., Afonso C. L. Phylogenetic diversity among low-virulence Newcastle disease viruses from waterfowl and shorebirds and comparison of genotype distributions to those of poultry-origin isolates. Journal of Virology. 2007. T. 81(22). P. 12641-12653. https://doi.org/10.1128/JVI.00843-07
79. Kim L. M., King D. J., Guzman H., Tesh R. B., Travassos da Rosa A. P., Bueno R. Jr., Dennett J. A., Afonso C. L. Biological and phylogenetic characterization of pigeon paramyxovirus serotype 1 circulating in wild North American pigeons and doves. Journal of Clinical Microbiology. 2008. T. 46(10). P. 3303-3310. https://doi.org/10.1128/jcm.00644-08
80. Kommers G. D., King D. J., Seal B. S., Brown C. C. Virulence of pigeon-origin Newcastle disease virus isolates for domestic chickens. Avian Diseases. 2001. T. 45(4). P. 906-921.
81. Kommers G. D., King D. J., Seal B. S., Brown C. C. Virulence of six heterogeneous-origin Newcastle disease virus isolates before and after sequential passages in domestic chickens. Avian Pathology. 2003. T. 32(1). P. 81-93. https://doi.org/10.1080/0307945021000070750
82. Kosters J., Knoll M., Lutticken D. Protective effect of a homologous oil emulsion vaccine against paramyxovirus in pigeons. Praktische Tierarzt. 1986. T. 67(3). P. 216-218.
83. Krapez U., Steyer A. F., Slavec B., Barlic-Maganja D., Dovc A., Racnik J., Rojs O. Z. Molecular characterization of avian paramyxovirus type 1 (Newcastle disease) viruses isolated from pigeons between 2000 and 2008 in Slovenia. Avian Diseases. 2010. T. 54(3). P. 1075-1080. https://doi.org/10.1637/9161-111709-resnote.1
84. Kuiken T., Buijs P., van Run P., van Amerongen G., Koopmans M., van den Hoogen B. Pigeon paramyxovirus type 1 from a fatal human case induces pneumonia in experimentally infected cynomolgus macaques (*Macaca fascicularis*). Veterinary Research. 2017. T. 48(1). P. 80. https://doi.org/10.1186/s13567-017-0486-6
85. Kuiken T., Breitbart M., Beer M., Grund C., Höper D., van den Hoogen B., Kerkhoffs J. H., Kroes A. C. M., Rosario K., van Run P., Schwarz M., Svraka S., Teifke J., Koopmans M. Zoonotic infection with pigeon paramyxovirus type 1 linked to fatal pneumonia. Journal of Infectious Diseases. 2018. T. 218(7). P. 1037-1044. https://doi.org/10.1093/infdis/jiy036
86. Lamb R. A., Parks G. D. Paramyxoviridae: The viruses and their replication. In: Knipe, DM. Howley, P. M., editors. Fields Virology, Fifth ed. 1. Lippincott Williams & Wilkins; Wolters Kluwer, 2007. T. 2. P. 1449-1496.
87. Le L., Brasseur R., Wemers C., Meulemans G., Burny A. Fusion (F) protein gene of Newcastle disease virus: Sequence and hydrophobicity comparative analysis between virulent and avirulent strains. Virus Genes. 1988. T. 1(4). P. 333-350. https://doi.org/10.1007/bf00257097
88. Lippmann O. Human conjunctivitis due to the Newcastle-disease virus of fowls. American Journal of Ophthalmology. 1952. T. 35(7). P. 1021-1028. https://doi.org/10.1016/0002-9394(52)90568-
89. Liu H., Wang Z., Song C., Wang Y., Yu B., Zheng D., Sun C., Wu Y. Characterization of pigeon-origin Newcastle disease virus isolated in China. Avian Diseases. 2006. T. 50(4): P. 636-640. https://doi.org/10.1637/ 7618-042606R1.1

90. Lu X., Wang X., Zhan T., Sun Y., Wang X., Xu N., Liao T., Chen Y., Gu M., Hu S., Liu X., Liu X. Surveillance of class I Newcastle disease virus at live bird markets and commercial poultry farms in Eastern China reveals the epidemic characteristics. Virologica Sinica. 2021. T. 36(4). P. 818-822. https://doi.org/10.1007/s12250-021-00357-z
91. Mansour S. M. G., Mohamed F. F., Eid A. A. M., Mor S. K., Goyal S. M. Cocirculation of paramyxo- and influenza viruses in pigeons in Egypt. Avian Pathology, 2017. T. 46(4). P. 367-375. https://doi.org/10.1080/03079457.2017.1285391
92. Mase M., Kanehira K. Phylogenetic analysis of avian paramyxovirus serotype-1 in pigeons in Japan. Journal of Veterinary Medical Science. 2015. T. 77(8). P. 919-923. https://doi.org/10.1292/jvms.14-0684
93. Mayahi M., Shapouri M., Jafari R., Farsani M. Characterization of isolated pigeon paramyxovirus-1 (PMV-1) and its pathogenicity in broiler chickens. Veterinary Research Forum. 2017. T. 8(1). P. 15-21.
94. Meulemans G., van den Berg T. P., Decaesstecker M., Boschmans M. Evolution of pigeon Newcastle disease virus strains. Avian Pathology. 2002. T. 31(5). P. 515-519. https://doi.org/10.1080/0307945021000005897
95. Miller P. J., Koch G. Newcastle disease. In Swayne, D. E., Glisson, J. R., McDougald, L. R., Nolan, L. K., Suarez, D. L., Nair, V. (ed), Diseases of poultry, 13th ed Wiley-Blackwell, Hoboken, NJ. 2013. 89-138p.
96. Miller P. J., Decanini E. L., Afonso C. L. Newcastle disease: evolution of genotypes and the related diagnostic challenges. Infection, Genetics, and Evolution. 2010. T. 10(1). P. 26-35. https://doi.org/10.1016/j.meegid.2009.09.012
97. Mohamed M. A., Sokker S. M., Yousif Y. I., Saad F., Bastami M. (1980): Contagious paralysis of pigeons: A preliminary investigation on the occurrence of the disease in Egypt. Egyptian Veterinary Medical Association Journal. 1980. T. 40(1). P. 45-51.
98. Ogasawara T., Gotoh B., Suzuki H., Asaka J., Shimokata K., Rott R., Nagai Y. Expression of factor X and its significance for the determination of paramyxovirus tropism in the chick embryo. EMBO Journal. 1992. T. 11(2). P. 467-472. https://doi.org/10.1002%2Fj.1460-2075.1992.tb05076.x
99. OIE. Newcastle disease, Chapter 2.3.14. OIE Terrestrial Manual 2012: Manual of Diagnostic Tests and Vaccines for Terrestrial Animals. Paris: World Organisation for Animal Health. 2012. 576-589p. http://Www.Oie.Int/Fileadmin/Home/Eng/Health_standards/Tahm/2. 03.14_NEWCASTLE_DIS.Pdf. Vol. 1
100. OIE. Newcastle disease (infection with Newcastle disease virus). In Manual of Diagnostic Tests and Vaccines for Terrestrial Animals; World Organisation of Animal Health (Founded as Office International des Epizooties): Paris, France, 2021. Chapter 3.3.14.
101. O'Reilly P. J., McCullough S., Alexander D. J., De Burca M. Recent avian paramyxovirus infections on the island of Ireland. In Proceedings of the Commission of the European Communities Meeting on Virus Diseases of Poultry-New and Evolving Pathogens, Brussels, Belgium, 18–19 October 1994. 47-63p.
102. Panda A., Huang Z., Elankumaran S., Rockemann D. D., Samal S. K. Role of fusion protein cleavage site in the virulence of Newcastle disease virus. Microbial Pathogenesis. 2004. T. 36(1). P. 1-10. https://doi.org/10.1016/j.micpath.2003.07.003
103. Pereira M. R., Machado L. C., de Oliveira Carvalho R. D., de Lima Cavalcanti T. Y. V., da Silva Filho G. B., de Sousa Lima T., Fonseca S. M. C., de Assis Leite Souza F., da Luz Wallau G., de Souza Mendonça F., de Oliveira Franca R. F. Identification of a virulent Newcastle disease virus strain isolated from pigeons (*Columbia livia*) in Northeastern Brazil using next-generation genome sequencing. Viruses. 2022. T. 14(7). P. 1579. https://doi.org/10.3390/v14071579
104. Pestka D., Stenzel T., Koncicki A. Occurrence, characteristics and control of pigeon paramyxovirus type 1 in pigeons. Polish Journal of Veterinary Sciences 2014. T. 7(2). P. 379-384. https://doi.org/10.2478/pjvs-2014-0056
105. Pienaar A. C. E., Cilliers J. A. The isolation of a paramyxovirus from pigeons in South Africa. Onderstepoort Journal of Veterinary Research. 1987. T. 54(4). P. 653-654.
106. Polten B. M., Kaleta E. F., Meister J. A. Further studies of vaccines for immunizing pigeons against paramyxovirus–1 infection. Die Deutsche Veterinärmedizinische Gesellschaft. 1985. T. 207. P. 218.
107. Prajna N. V., Lalitha P., Chen C., Zhong L., Lietman T. M., Doan T., Seitzman G. D. Acute keratoconjunctivitis resulting from coinfection with avian Newcastle virus and human adenovirus. Cornea. 2022. T. 41(5). P. 630-631. https://doi.org/10.1097/ico.0000000000002853
108. Qiu X., Meng C., Zhan Y., Yu S., Li S., Ren T., Yuan W., Xu S., Sun Y., Tan L., Song C., Liao Y., Ding Z., Liu X., Ding C. Phylogenetic, antigenic and biological characterization of pigeon paramyxovirus type 1 circulating in China. Virology Journal. 2017. T. 14(1). P. 186. https://doi.org/10.1186/s12985-017-0857-7
109. Rezaei Far A., Peighambari S. M., Pourbakhsh S. A., Ashtari A., Soltani M. Co-circulation of genetically distinct groups of avian paramyxovirus type 1 in pigeon Newcastle disease in Iran. Avian Pathology. 2017. T. 46(1). P. 36-43. https://doi.org/10.1080/03079457.2016.1203068
110. Sabra M., Dimitrov K. M., Goraichuk I. V. Wajid A., Sharma P., Williams-Coplin D., Basharat A., Rehmani S. F., Muzyka D. V., Miller P. J. Phylogenetic assessment reveals continuous evolution and circulation of pigeon-derived virulent avian avulaviruses 1 in Eastern Europe, Asia, and Africa. BMC Veterinary Research. 2017. T. 13. P. 291. https://doi.org/10.1186/s12917-017-1211-4
111. Schemera B., Toro H., Herbst W., Kaleta E. F. Conjunctivitis and general symptoms in man induced by the Newcastle disease virus. Deutsche Tieraerztliche Wochenschrift. 1987. T. 94. P. 383-384.
112. Shakal M. A. Studies on paramyxovirus infection in pigeons in Egypt. PhD thesis, Poultry Diseases, Faculty of Veterinary Medicine, Cairo University, Egypt. 1989.
113. Smietanka K., Minta Z. Isolation of an atypical pigeon paramyxovirus type 1 in Poland. Polish Journal of Veterinary Science. 2011. T. 14(1). P. 141-143. https://doi.org/10.2478/v10181-011-0021-z
114. Śmietanka K., Olszewska M., Domańska-Blicharz K., Bocian A. L., Minta Z. Experimental infection of different species of birds with pigeon paramyxovirus type 1 virus--evaluation of clinical outcomes, viral shedding, and distribution in tissues. Avian Diseases. 2014. T. 58(4). P. 523-530. https://doi.org/10.1637/10769-011514-reg.1
115. Snoeck C. J., Owoade A. A., Couacy-Hymann E., Alkali B. R., Okwen M. P., Adeyanju A. T., Komoyo G. F., Nakouné E., Le Faou A., Muller C. P. High genetic diversity of Newcastle disease virus in poultry in West and Central Africa: cocirculation of genotype XIV and newly defined genotypes XVII and XVIII. Journal of Clinical Microbiology. 2013. T. 51, P. 2250-2260. https://doi.org/10.1128/JCM.00684-13
116. Soliman Y. A., Eman M. S. El-Nagar, Abd-wlanees N. A., El-Safty M. Genetic analysis of pigeon paramyxo virus type 1 isolated in Egypt during 2014. Veterinary Medical Journal. 2016. T. 62(2). P. 59-74.
117. Soliman Y. A., Eman M. S. El-Nagar, Abd-wlanees N. A., El-Safty M. Efficacy of prepared oil inactivated pigeon paramyxo vaccine. Alexandria Journal of Veterinary Sciences. 2019. T. 60(1). P. 30-40. http://dx.doi.org/10.5455/ajvs.5378
118. Souza S. O. F., Fredo G., Dupont P. M., Leite-Filho R. V., Teifke J. P., Pavarini S. P., Canal C. W., Driemeier D. Pathological and molecular findings of avian avulavirus type 1 outbreak in pigeons (*Columba livia*) of southern Brazil. Pesquisa Veterinaria Brasileira. 2018. T. 38(12). P. 2254-2261. https://doi.org/10.1590/1678-5150-PVB-5528
119. Steele J. H., Beran G. W. CRC handbook series in zoonoses. Sect B: Viral Zoonoses. 1981. 261-627p.
120. Steward M., Vipond I. B., Millar N. S., Emmerson P. T. RNA editing in Newcastle disease virus. Journal of General Virology. 1993. T. 74(Pt 12). P. 2539-2547. https://doi.org/10.1099/0022-1317-74-12-2539

121. Stone H. D. Efficiency of oil emulsion vaccines prepared with pigeon paramyxovirus– 1 ulster and LaSota Newcastle disease virus. Avian Diseases. 1989. T. 33(1). P. 157-162.
122. Susta L., Miller P. J., Afonso C. L., Brown C. C. Clinicopathological characterization in poultry of three strains of Newcastle disease virus isolated from recent outbreaks. Veterinary Pathology. 2011. T. 48(2). P. 349-360. https://doi.org/10.1177/0300985810375806
123. Suarez D. L., Miller P. J., Koch G., Mundt E., Rautenschlein S. Newcastle disease, other avian paramyxoviruses, and avian metapneumovirus infections. In Diseases of Poultry, 14th ed.; Swayne, D. E., Boulianne, M., Logue, C. M., Mcdougald, L. R., Nair, V., Suares, D. L., Eds.; Wiley Blackwell: Hoboken, NJ, USA, 2020; Volume 1, pp. 109–166, ISBN 978-1-119-37116-8.
124. Swayne D. E., King D. J. Avian influenza and Newcastle disease. Journal of the American Veterinary Medical Association. 2003. T. 222(11). P. 1534-1540. https://doi.org/10.2460/javma.2003.222.1534
125. Teske L., Ryll M., Rautenschlein, S. Epidemiological investigations on the role of clinically healthy racing pigeons as a reservoir for avian paramyxovirus-1 and avian influenza virus. Avian Pathology. 2013. T. 42(6). P. 557-565. https://doi.org/10.1080/03079457.2013.852157
126. Thomazelli L. M., Sinhorini J. A., Oliveira D. B. L., Knobl T., Bosqueiro T. C. M., Sano E., Costa G. C. V., Monteiro C., Dorlass E. G., Utecht N., Scagion G. P., Meneguin C., Silva L. M. N., Moraes M. V. S., Bueno L. M., Reischak D., Carrasco A. O. T., Arns C. W., Ferreira H. L., Durigon E. L. An outbreak in pigeons caused by the subgenotype VI.2.1.2 of Newcastle disease virus in Brazil. Viruses. 2021. T. 13(12). P. 2446. https://doi.org/10.3390/v13122446
127. Tian Y., Xue R., Yang W., Li Y., Xue J., Zhang G. Characterization of ten paramyxovirus type 1 viruses isolated from pigeons in China during 1996-2019. Veterinary Microbiology. 2020. T. 244. P. 108661. https://doi.org/10.1016/j.vetmic.2020.108661
128. Ujvari D., Wehmann E., Herczeg J., Lomniczi B. Identification and subgrouping of pigeon type Newcastle disease virus strains by restriction enzyme cleavage site analysis. Journal of Virological Methods. 2006. T. 131(2). P. 115-121. https://doi.org/10.1016/j.jviromet.2005.07.012
129. Viaene N., Spanoghe L., Devriese L., Devos A. Paramyxovirus infection in pigeons. Vlaams Diergeneesk Tijdschr, 1983. T. 53. P. 278-286.
130. Viaene N., Spanoghe L., Devriese L., Devos A. Vaccination trials against paramyxovirus in pigeons. Vlaams Diergeneeskundig Tijdschrif, 1984. T. 53. P. 45-52.
131. Vindevogel H., Duchatel J. J. Vaccination assessments of pigeons against paramyxovirus type 1 infection with inactivated vaccines. VIIIth International Congress W.V.P.A., Jerusalem, 1985. 119p.
132. Vindevogel H., Marlier D. Viral infections in pigeons. Veterinary Journal. 2006. T. 172(1). P. 40-51. https://doi.org/10.1016/j.tvjl.2005.02.026
133. Vindevogel H., Thiry E., Pastoret P. P., Meulemans G. Lentogenic strains of Newcastle disease virus in pigeons. Veterinary Record. 1982. T. 110(21). P. 497-499. https://doi.org/10.1136/vr.110.21.497
134. Wang J., Liu H., Liu W., Zheng D., Zhao Y., Li Y., Wang Y., Ge S., Lv Y., Zuo Y., Yu S., Wang Z. Genomic characterizations of six pigeon paramyxovirus type 1 viruses isolated from live bird markets in China during 2011 to 2013. PLoS One. 2015. T. 10(4). P. e0124261. https://doi.org/10.1371/journal.pone.0124261
135. Wakamatsu N., King D. J., Kapczynski D. R., Seal B. S., Brown C. C. Experimental pathogenesis for chickens, turkeys, and pigeons of exotic Newcastle disease virus from an outbreak in California during 2002–2003. Veterinary Pathology. 2006. T. 43(6). P. 925-933. https://doi.org/10.1354/vp.43-6-925
136. Wawizkiewicz J., Pockodyla A., Kania W., Gasiorczyk A. PM-VAC, a vaccine against pigeon paramyxoviruses. Medycyna Weterynaryjna. 1991. T. 47 (3). P. 108-110.
137. Wei T., Deng Q., Li H., Pan C., Zhai G., Yuan Y., Cheng E., Zhang Y., Mo M., Huang T., Wei P. Molecular characterization of two novel sub-sublineages of pigeon paramyxovirus type 1 in China. Archives of Virology. 2018. T. 163(11). P. 2971-2984. https://doi.org/10.1007/s00705-018-3950-3
138. Werner O., Römer-Oberdörfer A., Köllner B., Manvell R. J., Alexander D. J. Characterization of avian paramyxovirus type 1 strains isolated in Germany during 1992 to 1996. Avian Pathology. 1999. T. 28(1). P. 79-88. https://doi.org/10.1080/03079459995082
139. Winter S., Lechapt E., Gricourt G., N'Debi M., Boddaert N., Moshous D., Blauwblomme T., Kossorotoff M., Fouyssac F., Chareyre J., Demontant V., Chretien F., Woerther P. L., Pawlotsky J. M., Blanche S., Neven B., Rodriguez C. Fatal encephalitis caused by Newcastle disease virus in a child. Acta Neuropathologica. 2021. T. 142(3). P. 605-608. https://doi.org/10.1007/s00401-021-02344-w
140. Xie P., Chen L., Zhang Y., Lin Q., Ding C., Liao M., Xu C., Xiang B., Ren T. Evolutionary dynamics and age-dependent pathogenesis of sub-genotype VI.2.1.1.2.2. Viruses. 2020. T. 12(4). P. 433. https://doi.org/10.3390/ v12040433
141. Yang C. Y., Shieh H. K., Lin Y. L., Chang P. C. Newcastle disease virus isolated from recent outbreaks in Taiwan phylogenetically related to viruses (genotype VII) from recent outbreaks in Western Europe. Avian Diseases. 1999. T. 43(1). P. 125-130. https://doi.org/10.2307/1592771
142. Zanetti F., Mattiello R., Garbino C., Kaloghlian A., Terrera M. V., Boviez J., Palma E., Carrillo E., Berinstein A. Biological and molecular characterization of a pigeon paramyxovirus type-1 isolate found in Argentina. Avian Diseases. 2001. T. 45. P. 567-571. https://doi.org/10.2307/1592896
143. Zehetbauer G., Kunz C., Thaler A. Cases of pseudo fowl plaque (Newcastle disease) in man in Lower Austria. Wiener Klinische Wochenschrift. 1971. T. 83(48). P. 878-880.
144. Zhan T., Hu S., Chen Y., Lu X., Liao T., Guo L., Gao X., Xu X., Hu Z., Liu X., Wang X., Liu X. Comparative pathogenicity of two closely related Newcastle disease virus isolates from chicken and pigeon respectively. Virus Research. 2020. T. 286. P. 198091. https://doi.org/10.1016/j.virusres.2020.198091
145. Zhan T., Lu X., He D., Gao X., Chen Y., Hu Z., Wang X., Hu S., Liu X. Phylogenetic analysis and pathogenicity assessment of pigeon paramyxovirus type 1 circulating in China during 2007-2019. Transboundary and Emerging Diseases. 2022. T. 69(4). P. 2076-2088. https://doi.org/10.1111/tbed.14215
146. Zhao B., Fu Y., Fan J., Xu B., Bu Z., Gao M., Chen W., Sun X. Development of bivalent inactivated oil-emulsion vaccine against pigeon paramyxovirus disease. Jiangsu Journal of Agricultural Sciences. 2010. T. 26. P. 1293-1297.
147. Zou X., Suo L., Wang Y., Cao H., Mu S., Wu C., Yan L., Qi X., Lu J., Lu B., Fan Y., Li H., Huang L., Ren L., Liu B., Cao B. Concurrent pigeon paramyxovirus-1 and *Acinetobacter baumannii* infection in a fatal case of pneumonia. Emerging Microbes & Infections. 2022. T. 11(1). P. 968-977. https://doi.org/10.1080/22221751.2022.2054366

Received 4 March 2023
Accepted 13 May 2023