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Newcastle Disease Virus Infection in Domestic Pigeons: Epidemiology, Pathogenesis, Diagnosis, and Vaccination Strategies with Emphasis on Chitosan Nanoparticles

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ABSTRACT

Newcastle disease virus (NDV), also known as avian paramyxovirus-1 (APMV-1), is a highly contagious pathogen that affects most avian species, including domestic pigeons (*Columba livia*), leading to Newcastle disease (ND). The ND in pigeons is attributed to pigeon-specific strains of NDV, predominantly characterized by the emergence of pigeon paramyxovirus-1 (PPMV-1). This viral strain is specifically adapted to affect avian species, particularly within the pigeon population, resulting in distinct pathological features associated with the disease. The ND was correlated with severe respiratory, neurological, and gastrointestinal manifestations, resulting in elevated morbidity and mortality rates, which may reach up to 80%. The present study provided an updated overview of the pathogenesis, clinical and pathological features, and diagnostic approaches related to NDV infection in domestic pigeons worldwide. Conventional and modern vaccination strategies were discussed in the present study, with a focus on mucosal immunization. Chitosan-based nanoparticles (CS-NPs) have emerged as a promising vaccine delivery platform due to their compatibility with biological systems, strong adhesion to mucosal surfaces, and ability to enhance antigen stability and stimulate the immune response. The CS-NPs improved antigen uptake at mucosal surfaces in poultry and stimulated both humoral and cellular immune responses, which included activating cytotoxic T cells, producing cytokines, and secreting immunoglobulins at mucosal sites. The present review may contribute to the advancement of more effective and targeted vaccine strategies against NDV in pigeons and other avian species.

Keywords: Chitosan, Live vaccine, Nanoparticle, Newcastle disease, Paramyxovirus, Pigeon

INTRODUCTION

Newcastle disease virus (NDV) is the causative agent of Newcastle disease (ND), a highly contagious infection affecting poultry. The economic impact of ND is significant, posing considerable challenges to the poultry industry worldwide (Mao et al., 2022). The ND was first reported in 1926 on Java Island, Indonesia, and in Newcastle-upon-Tyne, England; the disease later spread worldwide, causing substantial economic losses to the poultry industry (Mao et al., 2022; Dharmayanti et al., 2023). The ND is endemic in parts of Asia (Ansori and Kharisma, 2020), Africa (Ansori and Kharisma, 2020), the Middle East (Dzogbema et al., 2021), Central and South America, and Indonesia (Dharmayanti et al., 2023).

The NDV, recognized as avian paramyxovirus-1 (APMV-1), belongs to the family Paramyxoviridae, subfamily Avulavirinae, genus Orthoavulavirus, and species avian paramyxovirus 1 (Zerbini et al., 2024). The NDV possesses an envelope and carries a single-stranded, negative-sense RNA genome (Biswas et al., 2024). The RNA genome encodes six structural proteins, including nucleoproteins (NP), phosphoproteins (P), matrix protein (M), fusion protein (F), hemagglutinin-neuraminidase (HN), and large polymerase protein (L) (Moustapha et al., 2023). The complete nucleotide sequence of the *F* gene indicates that the virus is categorized into class I, which contains a single genotype, and class II, which comprises 20 genotypes (I-XXI) (da Silva et al., 2020). The classification of NDV pathogenicity encompasses

velogenic, mesogenic, lentogenic, and asymptomatic categories, based on intracerebral pathogenicity index (ICPI) values of over 1.5, between 1.5 and 0.7, less than 0.7, and 0, respectively (Dzogbema et al., 2021). The velogenic NDV pathotype (Viscerotropic and neurotropic) shows very high mortality, the mesogenic pathotype reveals moderate respiratory signs and low mortality, the lentogenic strain induces a mild respiratory infection with no mortality, and the asymptomatic pathotype may exhibit no clinical signs or subclinical enteric infection in poultry (Nurzijah et al., 2022).

The domestication of the pigeon (*Columba livia*) dates back approximately 6,000 years, originating during the Neolithic period in the Mesopotamian Valley (Giunchi et al., 2020). The selection of different domestic pigeon breeds marks the early stages of their development. The pigeon industry has grown into a diverse sector, including birds used for racing, ornamental purposes, and meat production (Gao et al., 2016; Jin et al., 2023). Pigeon meat and eggs are highly nutritious and have become a popular food source worldwide. Recently, the domestic pigeon farming industry has evolved as a significant component of the poultry sector (Wang et al., 2025). Pigeons are susceptible to many important viral, bacterial, fungal, and parasitic diseases; one of the significant infections of pigeons is APMV-1 (Abd El-Ghany, 2023). Pigeons are effective carriers of APMV genotype VIId (Velogenic viscerotropic strain) due to the cross-transmission of the virus among avian species (He et al., 2018). Infected pigeons exhibit high mortality rates exceeding 75%, accompanied by severe digestive (Greenish diarrhoea), respiratory (Dyspnoea, rales), and neurological signs (Torticollis, paralysis), as well as high viral shedding in the trachea and cloaca (Thomazelli et al., 2021).

Infectious viral diseases in poultry, particularly those affecting the respiratory system, pose a significant threat, resulting in severe economic losses, as well as their zoonotic importance (Biswas et al., 2024; Hassman et al., 2025; Kilany et al., 2025). Due to the difficulties in controlling viral diseases, vaccination is the only recommended method to prevent and overcome viral diseases (Moustapha et al., 2023). Vaccines against viral infections include live (Naturally weak or attenuated), killed or inactivated, subunit, or recombinant types (Abdelaziz et al., 2024). The development of innovative vaccines aims to induce specific adaptive immune responses that protect chickens against different viral diseases, which can be achieved by optimizing factors such as the route of administration, the use of effective adjuvants, and the implementation of a well-structured vaccination program (Yu et al., 2020). However, delivering the vaccine antigen can be hindered by several barriers, including low immunogenicity, degradation within the body, and the risk of inducing immune tolerance (Moghaddam, 2021). To address the challenges associated with conventional vaccine delivery mechanisms, there has been a growing interest in carbohydrate-based polysaccharides as effective agents for improving vaccine efficacy. Notably, chitin, a naturally occurring biopolymer sourced from insects and crustaceans, emerges as a particularly significant candidate due to its abundant availability and potential application in vaccine formulation (Renu and Renukaradhya, 2020). The deacetylation of the chitin polysaccharide chain produces chitosan. Chitosan is extensively utilised to target mucosal areas via oral, ophthalmic, nasal, implant, parenteral, and transdermal routes owing to its distinctive characteristics, including modifiable flexibility, positive surface charge, and the ability to conjugate with other polymers (Renu and Renukaradhya, 2020; Guo et al., 2024). Additionally, chitosan is known for its bioavailability, biodegradability, safety, and immunostimulatory properties, making it a suitable carrier for all types of vaccines (Wijesekara and Xu, 2024).

The mucosal immunity triggered by viral vaccines is achieved through precise and optimal delivery methods (Nasal and oral) in most poultry species (Akter et al., 2024). The mucosal immune response begins with microfold cells, specialized epithelial cells located in the mucosa-associated lymphoid tissue, mainly in the Peyer patches of the small intestine. These cells take up the CS-NP-based vaccines and then transport the nanoparticles to areas rich in antigen-presenting cells (Jazayeri et al., 2021). This process activates antigen-specific CD4+ T helper (Th) cells, which then interact with B lymphocytes, encouraging their differentiation into IgA-committed B cells (IgA+ B cells). These IgA+ B cells migrate to mucosal effector sites, where they further mature into plasma cells that produce immunoglobulin A (IgA) (Jin et al., 2019; Thakur and Foged, 2020). Meanwhile, the cellular immune response is initiated by antigen-presenting cells (APCs), such as dendritic cells, macrophages, and B lymphocytes. These APCs stimulate the development of cytotoxic T lymphocytes (CTL) by activating CD8+ T cells and CD4+ T helper type 1 (Th1) cells (Renu and Renukaradhya, 2020; Guo et al., 2024).

The present study aimed to provide an updated overview of NDV infection in domestic pigeons, including pathogenesis, clinical features, and diagnostic methods, highlighting current vaccination challenges and exploring the potential of chitosan-based nano vaccines as an innovative approach for mucosal immunization against NDV in pigeons.

PARAMYXOVIRUS INFECTION IN PIGEONS

Pigeons are highly susceptible to NDV infection, resulting in significant economic losses due to immunosuppression, mortality, and vaccination costs. Additionally, outbreaks of NDV in pigeons can result in trade limitations regarding the movement of live birds and involvement in exhibitions or races, especially in accordance with international animal health regulations (Abd El-Ghany, 2023). The NDV that affects pigeons of all ages is an antigenic variant of APMV-1, known as pigeon paramyxovirus type 1 (PPMV-1), which belongs to the genus *Orthoavulavirus*, subfamily Avulavirinae, within the family Paramyxoviridae (Zerbini et al., 2024).

Over the past three to five years, there has been a significant increase in APMV-1 infections among pigeons, causing substantial losses in the global poultry and pigeon breeding industries (Tong et al., 2024). The PPMV-1 is a host-adapted variant of the traditional NDV genotype VI in chickens and pigeons (Abd El-Ghany, 2023; Tong et al., 2024). Some recent PPMV-1 demonstrated the virulence of mesogenic strains, as evidenced by the mean death time of chicken embryos, which was recorded at 76.8 hours, and an ICPI of 1.25. The morbidity and mortality rates in pigeons were recorded at 100% and 80%, respectively, while chickens exhibited both rates at 80%. Consequently, these recent PPMV-1 isolates were determined to be velogenic for both species (Tong et al., 2024). The ND in pigeons is known as paramyxovirus, which leads to neurological symptoms and high mortality rates, especially in those infected with viscerotropic strains (Pestka et al., 2014; Abdulrasool and Seger, 2023). Currently, PPMV-1 has been documented as an enzootic infection affecting racing, feral, and fancy pigeons (Alexander, 2011; Abd El-Ghany, 2023). Young pigeons (4-6 months old) are the most susceptible to PPMV-1 infection (Badr et al., 2022).

The first identification of APMV-1 in pigeons occurred in Egypt in 1967 (Mansour et al., 2021). More cases of pigeons showing neurological symptoms have been recorded (Elbhnsawy et al., 2017; Mansour et al., 2021; Abd El-Ghany, 2023). Furthermore, PPMV-1 was initially isolated in the Middle East, specifically in Iraq, in 1978. Kaleta et al. (1985), Pestka et al. (2014), and Abdulrasool and Seger (2023) provided a comprehensive characterization of the PPMV-1. During the early 1980s, outbreaks were reported in Europe and North America among pigeons, which occasionally spread to domestic poultry (Kaleta et al., 1992; Rogers et al., 2021). The global spread and evolution of PPMV-1, from early detections to modern outbreaks, are summarized in Table 1 (Rogers et al., 2021; Abd El-Ghany, 2023). Pigeons of all ages have been infected with PPMV-1, showing high morbidity and mortality (Abd El-Ghany, 2023; Abdulrasool and Seger, 2023). The PPMV-1 constantly circulates in healthy feral pigeons, which serve as asymptomatic carriers transmitting the virus to free-range chickens (Annaheim et al., 2022). Sub-genotype XXI.2 of PPMV-1 has been reported in collared doves in Italy and Iran and wild doves in North America (Esmaeelzadeh-Dizaji et al., 2022). The PPMV-1 virus is highly virulent in pigeons, chickens, and turkeys, while quails and geese tend to resist infection (Alexander, 2011; Abd El-Ghany, 2023). Passaging in chickens increases its virulence (Śmietanka et al., 2014; Tong et al., 2024). Although some migratory pigeons might transmit the virus, documented cases of infection are restricted to members of the Columbiformes order, such as pigeons and doves, and have not been seen in species outside this group (Dortmans et al., 2011; Abd El-Ghany, 2023). The PPMV-1 virus spreads through nasal, buccal, and ocular secretions, as well as droppings from infected pigeons. Horizontal transmission happens through inhalation or ingestion; additionally, direct contact between healthy and infected pigeons accelerates the spread of the virus (Annaheim et al., 2022; Al-Hially et al., 2024).

CLINICAL SIGNS AND PATHOLOGY OF PIGEON PARAMYXOVIRUS TYPE 1 IN INFECTED PIGEONS

The incubation period of Paramyxovirus type 1 (PMV-1) infection in pigeons ranges from 7 to 14 days, with the severity of clinical manifestations influenced by the virulence of the infective strain, the host's immune status, and any concurrent infections (Alexander and Senne, 2008; Abd El-Ghany, 2023). Pigeons infected with PMV-1 often show clinical signs similar to those caused by neurotropic velogenic strains (Badr et al., 2022; Tong et al., 2024). Pigeons often exhibit polyuria and neurological signs, such as torticollis, shaking, head nodding, muscular tremors, and paralysis of the wings and legs (Figure 1), along with the potential for greenish diarrhea (Badr et al., 2022; Abd El-Ghany, 2023; Al-Hially et al., 2024).

Respiratory signs and swollen eyelids with a serous discharge may occasionally be observed in infected pigeons. As reported by Kraidi et al. (2024), mortality usually starts within five days after infection, and the pigeon dies throughout the observation period of 15 days. Post-mortem findings in pigeons infected with PPMV-1 are often variable and may be nonspecific. However,

several key lesions have consistently been identified, including haemorrhages in the brain (Figure 2), petechial haemorrhages in the gizzard, hemorrhagic enteritis, liver congestion, and soft or friable brain tissue (Badr et al., 2022; Abd El-Ghany, 2023; Al-Hially et al., 2024).

The histopathological changes include alterations in meningeal capillaries, hemorrhages in brain tissue, vacuolar degeneration, vasogenic oedema, and gliosis (Pereira et al., 2022; Al-Hially et al., 2024). Other affected organs exhibited interstitial haemorrhages, accompanied by significant epithelial sloughing of the renal tubular epithelium. Additionally, there was marked white pulp hyperplasia and peri-arteriolar fibrosis, giving a characteristic onion skin appearance in the spleen (Yuzbasioglu-Ozturk and Gurel, 2022). The infiltration of mononuclear cells was observed in the pigeon intestine, characterised by necrosis, severe destruction of the superficial intestinal mucosa, and intense inflammation at the site of tissue destruction (Thomazelli et al., 2021; Yuzbasioglu-Ozturk and Gurel, 2022).

CROSS-TRANSMISSION OF PARAMYXOVIRUSES BETWEEN PIGEONS AND CHICKENS

Pigeons are considered a significant threat for transmitting NDV to domestic chickens because of their migratory behavior, free-living activities, and presence in live bird markets and backyard settings. As a natural host of APMV-1, they play a vital role in the virus's ecology (Pestka et al., 2014; Abd El-Ghany, 2023).

Further evidence of chicken susceptibility to PPMV-1 came from experimental infection of 5-week-old chickens with pigeon-derived NDV of genotype XXI (Nooruzzaman et al., 2021; Tong et al., 2024). Infected chickens exhibited notable pathogenic changes in the lungs, thymus, spleen, and bursa of Fabricius, along with a high mortality rate of approximately 85% and typical signs of NDV. Additionally, histological examination of the brains of infected chickens revealed glial hyperplasia and neuronal degeneration (Zhang et al., 2023). Remarkably, multiple passages of PPMV-1 in chickens may increase its virulence, leading to more severe disease manifestations and heightened neuro-invasiveness (Dortmans et al., 2011; Tong et al., 2024). Several NDV outbreaks in chickens have been associated with spillover events from PPMV-1, and genetic studies have identified specific point mutations that increase the pathogenicity of PPMV-1 in chickens (Werner et al., 1999; Dortmans et al., 2009; Abd El-Ghany, 2023).

DIAGNOSIS STRATEGIES

The signs of PPMV-1 infection closely resemble those of pigeon herpesvirus infection, vitamin B1 deficiency, sodium chloride toxicity, and ronidazole overdose (Pestka et al., 2014; Hamouda et al., 2017; Abd El-Ghany, 2023). This shared feature can complicate clinical diagnosis; therefore, laboratory diagnosis is essential.

The clinical signs and pathological lesions related to the disease are not considered definitive diagnostic tools; however, they may provide preliminary indications that support a tentative diagnosis (Moustapha et al., 2023). Therefore, direct viral antigen detection through viral isolation and identification from swabs of live pigeons or organs taken from deceased ones is the most effective method for a definitive diagnosis of NDV (Prasad et al., 2024). Virus isolation can be effectively performed using embryonated chicken eggs aged 9 to 11 days or different cell types, such as chicken embryo hepatocytes, fibroblasts, reticulum cells, and African monkey kidney cells (WOAH, 2024). Following incubation at 37°C for 4 to 7 days, the propagated eggs were stored at +4°C; after harvesting the allantoic fluid, the NDV was detected by analyzing the allantoic fluid through a hemagglutination assay and confirming NDV infection by a hemagglutination inhibition (HI) test or molecular techniques, such as reverse transcription polymerase chain reaction (RT-PCR) or real-time PCR (Moustapha et al., 2023; WOAH, 2024). Additionally, NDV is identified by other serological methods, including fluorescent antibody tests, agar gel immunodiffusion techniques, hemolysis tests, or electron microscopy through identification of viral particle morphology (Moustapha et al., 2023).

Serological diagnosis using the HI test was typically employed as a confirmatory method, relying on specific antibodies to inhibit the hemagglutination activity of NDV (WOAH, 2024). Another serological test often used is the indirect enzyme-linked immunosorbent assay (ELISA), in which the viral antigens are first coated onto a microtiter plate. Serum from the test subject, such as pigeons, is then added, allowing specific antibodies to bind to the target antigen. Secondary antibodies, typically derived from another species and conjugated to an enzyme, including horseradish peroxidase, are introduced to produce a colorimetric reaction when the substrate (TMB) is added. The resulting color intensity is measured by a spectrophotometer at 450 nm, indicating antibody levels (Dzogbema et al., 2021; Moustapha et al., 2023). This method has been successfully applied in the diagnosis of PPMV-1 infection, as demonstrated by Yuzbasioglu-

Ozturk and Gurel (2022), who used ELISA to test sera from pigeons in Istanbul. The ELISA identified 89.18% of cases as positive, confirming its reliability as a diagnostic tool in field investigations. Additional serologic techniques, such as virus neutralization tests, immunofluorescence assays, and colloidal gold-based immunoassays, are employed to detect antibodies against NDV (Mao et al., 2022).

Additional significant methods, including nested PCR, fluorogenic probe-based RT-PCR, ligase chain reaction, SYBR Green intercalation, and light-extended fluorogenic primer assays, have been developed (Dzogbema et al., 2021; Mao et al., 2022). Despite their promising potential, these assays encounter several limitations, particularly in the detection of different viral strains, such as the distinct genotypes of NDV, including genotypes I, II, VII.1.1, and VII.2, as well as strains exhibiting mutations in the *F* gene cleavage site. These challenges underscore the necessity for further validation to establish the reliability and efficacy of these assays in a broader diagnostic context (Moustapha et al., 2023). Since the NDV *F* gene is essential in affecting viral pathogenicity, RT-PCR assays for NDV pathotyping mainly focus on this gene (Abd Elfatah et al., 2021; Moustapha et al., 2023). A novel real-time reverse transcription isothermal loop-mediated amplification method has recently been introduced, providing quicker and more precise detection compared to real-time RT-PCR (Song et al., 2023).

CONTROL AND VACCINATION STRATEGIES

As both immune complex vaccines and *in ovo* injection are widely used advanced strategies in poultry immunization programs, they play a crucial role in early and effective disease control (Abd El-Ghany, 2025). Immune complex vaccines are crucial for early-life immunization, in which the live virus is bound to specific antibodies, creating a complex. The formed antibody-virus complex slows down the release of the PPMV-1 in the pigeons' bodies, helping it to evade maternal antibodies and activate immunity at the optimal time. The immune complex vaccines are frequently used to combat infectious bursal disease and, in some instances, ND (Marchenko and Kolechko, 2024). On the other hand, *in ovo* vaccination, typically performed at 18 days of embryonic development, involves injecting attenuated ND vaccines directly into the egg. This method provides consistent vaccine delivery, quick protection after hatch, and less labor, making it a safe and effective way for large-scale immunization programs (Hu et al., 2022; Abd El-Ghany, 2025).

Controlling PMV-1 infection in pigeons depends on strict biosecurity measures to prevent viral contact and effective vaccination strategies. For NDV, traditional live and inactivated vaccines, along with advanced recombinant and antigen-matched vaccines, have been widely used, with strains such as Ulster, LaSota, and Mukteshwar being particularly effective (Nurzijah et al., 2022; Moustapha et al., 2023). Recent advances in genetic engineering have enabled the development of advanced multipurpose vaccines, such as virus-like particle vaccines for ND. These vaccines mimic the virus's outer structure without containing its genetic material, making them both safe and effective. Moreover, they are designed to differentiate between infected and vaccinated animals (DIVA) (Raji et al., 2024). Emerging plant-based vaccines demonstrated potential due to their DIVA capability and reduced shedding (Smith et al., 2023). For PPMV-1, vaccination remains crucial, with inactivated NDV vaccines, particularly those derived from lentogenic strains such as LaSota, providing significant protection (Viaene et al., 1984; Soliman et al., 2019; Abd El-Ghany, 2023). Homologous PPMV-1 vaccines are preferred due to their enhanced protective capabilities compared to heterologous NDV vaccines, which may not adequately replicate within pigeon tissues (Soliman et al., 2019; Abd El-Ghany, 2023). Since slow release of vaccinal antigen gives long immunity, homologous live and inactivated vaccines, especially those formulated with oil adjuvants, have been shown to elicit robust immune responses and provide long-lasting protection, with some studies reporting rates as high as 100% against homologous challenges (Amer et al., 2013; Hamouda et al., 2024). Regular updates to vaccine strains, including local field isolates, are essential for preserving effectiveness against evolving PPMV-1 sub-strains (Zhang et al., 2024).

Recent advances in NDV vaccine techniques have increasingly focused on utilizing nanotechnology to enhance protective efficacy, particularly through the use of chitosan nanoparticles, as seen in the development of live attenuated NDV vaccines encapsulated in chitosan for mucosal delivery (Renu and Renukaradhya, 2020). Traditional strategies focused on matching vaccination strains to circulating viruses, while modern methods use innovative delivery systems that enhance mucosal immunity and minimize viral shedding (Zhang et al., 2024).

Chitosan, a natural polysaccharide known for its bioavailability, biodegradability, safety, and immunostimulatory potential, functions effectively as a vaccine carrier (Wijesekara and Xu, 2024). However, one of the critical challenges in its application is its poor solubility at neutral pH (6 to 6.5), which restricts the delivery of soluble and stable antigens in natural pH conditions (Renu and Renukaradhya, 2020). Therefore, numerous structural modifications have been made to the

leading amino group of chitosan, including quaternization with N-2-hydroxypropyl trimethyl and N, O-carboxymethyl, to enhance water solubility without compromising its biological properties (Pathak et al., 2021). A common technique for forming CS-NPs-based vaccines involves mixing antigens with CS-NPs and inducing encapsulation using ionic gelation with sodium tripolyphosphate (Renu et al., 2020; Bugybayeva et al., 2024). This technique protects the vaccine virus from degradation, especially in the gastrointestinal tract of vaccinated animals such as pigs, which is a common reason for oral vaccine failure. As a result, oral and intranasal delivery methods for CS-NPs-encapsulated NDV vaccines have shown significant promise (Bernocchi et al., 2017; Masimov and Wasan, 2024).

Experimental studies have shown that the intranasal delivery of CS-NP-based NDV vaccines significantly boosts both mucosal and systemic immune responses. This results in the production of antigen-specific IgG and mucosal IgA, stimulates lymphocyte growth, and increases cytokine levels, including interleukins (IL-2) and IL-4, along with interferon-γ (IFN-γ). Ultimately, these immunological enhancements help to provide comprehensive protection against infection (Renu and Renukaradhya, 2020). These findings supported the increasing consensus on the improved immunogenicity and effectiveness of vaccines formulated with CS-NPs in poultry (Renu and Renukaradhya, 2020; Moghaddam, 2021), as further illustrated in Table 2. Despite these promising developments in the use of CS-NP-based NDV vaccines in poultry, no published studies have applied this delivery system for PPMV-1 vaccination in domestic pigeons (*Columba livia*).

Table 1. Global spread and incidence survey of pigeon paramyxovirus-1 infection

Region	Country/region	Year(s)	Isolation details
Middle East	Middle East	1978	First reported isolation of PPMV-1 in the Middle East in captive pigeons raised for meat.
Europe	United Kingdom (Liverpool docks)	1984	Feral pigeons contaminated feed at the Liverpool docks, leading to 19 NDV outbreaks in chickens.
	Ireland	1994	Isolation of PPMV-1 reported in Ireland.
	Slovenia	2000, 2008	PPMV-1 was isolated from pigeons between 2000 and 2008 in Slovenia.
	Macedonia	2007, 2008, 2010, 2011	Phylogenetically similar (NDV/chicken/Macedonia/231/2010)
	Italy (Eurasian collared doves)	1960s-2000 and 2001	Pigeon isolates of PPMV-1 have been reported in Italy. Mass mortality events in collared doves reach 90%.
Asia	Japan	1984, 1990s, 2000s, 2013	The PPMV-1 has been circulating in pigeon populations for a long period.
	China	1996-2018	Multiple isolations were reported in 2006, 2015, 2017, 2018, 2020, and 2022, indicating over 30 to 40 years of virus circulation in Chinese pigeon populations.
	Iran	2012-2018	Recurring isolation of PPMV-1 from pigeons in Iran was reported between 2012 and 2018, indicating sustained viral circulation during that period.
Africa	South Africa	1987, 2004, 2008	1987: Early outbreak of PPM-1 detection in pigeons.
	Egypt	1980, 1989, 1993, 2005, 2016, 2017	A series of isolations associated with PPMV-1 were reported.
Americas	Brazil	2001, 2018, 2021, 2022	A sequence of isolations from commercial and backyard pigeon outbreaks
	United States	1984, 1990	The PPMV-1 was first detected in captive and free-ranging feral pigeons in New York, then in California in 1990.
	United States (Florida, collared doves)	2001	A significant mortality event in collared doves, with ~5,000 deaths.
	United States (Western regions including AZ, TX, NV, and UT)	2009-2014	Recurring outbreaks in collared doves, with some native dove species, such as mourning, white-winged, and common ground doves, occasionally found dead, though confirmation in native species has been challenging.

PPMV-1: Pigeon paramyxovirus-1, NDV: Newcastle disease virus, AZ: Arizona, TX: Texas, NV: Nevada, UT: Utah.

Table 2. Summary of chitosan-based nanoparticle vaccines for Newcastle disease in poultry

Antigen encapsulated	Nanoparticle composition	Route of delivery	Immune responses	Country	Reference
Live NDV (LaSota strain)	Chitosan nanoparticles	Oral and intranasal	Enhanced mucosal and systemic immunity	China	Zhao et al. (2012)
NDV *F* gene plasmid DNA	Chitosan nanoparticles	Intranasal	Elevated serum IgG and mucosal IgA levels	China	Sun et al. (2014)
NDV *F* gene plasmid DNA	Ag@SiO_2 hollow nanoparticles	Intranasal	Significant mucosal IgA and systemic IgG responses	China	Zhao et al. (2016)
Different bacterial and viral antigens	Chitosan nanoparticles	Oral and Intranasal	Robust mucosal and systemic immunity	United States	Renu and Renukaradhya (2020)
NDV vaccine	O-2′-Hydroxypropyl trimethyl ammonium chloride chitosan nanoparticles	Intranasal	Enhanced mucosal and systemic immune responses	China	Zhao et al. (2021)
Genotype VII NDV	Chitosan nanoparticles	*In vitro* study	Demonstrated antiviral activity against NDV	Egypt	Alkhalefa et al. (2022)
Inactivated NDV and H9N2 avian influenza virus	N-2-Hydroxypropyl trimethyl ammonium chloride chitosan-aluminum sulfate composite nanoparticles (N-2-HACC-Al NPs)	Intra-muscular	Elevated serum IgG, IL-4, and IFN-γ levels	China	Liu et al. (2023)

NDV: Newcastle disease virus, NPs: Nanoparticles, IgG/IgA: Immunoglobulin G / A, IL-4: Interleukin-4, IFN-γ: Interferon gamma, H9N2: Subtype of avian influenza virus, *F* gene: Fusion gene of NDV, Ag@SiO_2: Silver-doped silica nanoparticle, N-2-HACC-Al NPs: N-2-hydroxypropyl trimethyl ammonium chloride chitosan–aluminium sulfate composite nanoparticles, O-2′-Hydroxypropyl trimethyl ammonium chloride chitosan: A water-soluble quaternised chitosan derivative.

Figure 1. Clinical signs in an 8-month-old domestic pigeon infected with pigeon paramyxovirus-1. The pigeon exhibits neurological manifestations, including torticollis and loss of equilibrium, which are characteristic signs of pigeon paramyxovirus-1 infection.

Figure 2. Gross lesions in the brain of an 8-month-old domestic pigeon infected with pigeon paramyxovirus-1. The brain shows multiple haemorrhages indicative of virus-induced vascular damage associated with pigeon paramyxovirus-1 infection.

CONCLUSION

Newcastle disease virus (NDV) infection remains a significant concern for avian health and poultry productivity worldwide, particularly in pigeons. While conventional control measures, such as vaccination with homologous PPMV-1 strains, have achieved variable success, the modern nanotechnology-based approaches have exhibited exceptional promise in vaccination strategies. Among these, chitosan nanoparticles (CS-NPs) have demonstrated notable potential in enhancing mucosal and systemic immunity against NDV in poultry. However, this novel delivery strategy has yet to be applied or validated in pigeons, presenting a significant opportunity for further studies and innovation. It is strongly recommended that future vaccination strategies for pigeons include CS-NPs-based mucosal vaccines, as this approach could improve immune responses and effectively decrease viral shedding.

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Authors' contributions

Muhammadtaher Abdulrazaq Abdulrasol conceptualized the topic, conducted the literature review, and prepared the initial manuscript draft. Wafaa A. Abd El-Ghany supervised the scientific content, reviewed the immunological and virological sections, and edited the manuscript. Harith Abdulla Najem contributed to organizing the vaccination strategies section and revised the manuscript linguistically. All authors have read and approved the final edition of the manuscript.

Availability of data and materials

The present article is a review paper and does not include original experimental data. However, any supporting materials or information can be provided upon request from the corresponding author.

Ethical considerations

The present article is a literature-based review that does not involve any animal or human experiments. The authors carefully observed and addressed ethical concerns regarding plagiarism, misconduct, data integrity, and duplicate publication.

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