https://doi.org/10.29326/2304-196X-2024-13-2-124-135

Infectious hematopoietic necrosis (review)

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ABSTRACT
Aquaculture in the Russian Federation is an integral part of the agricultural industry of the state economy. Countries with high rates of aquaculture growth (Norway, USA, China, Japan, Canada, etc.) and increasing efficiency of fish farming are the cradles of infectious diseases, which, in case of improper control, invade the territory of other countries and spread to new areas, bearing the risks for the domestic industry too. In recent years, infectious hematopoietic necrosis (IHN) has caused significant damage to fish farms. In 2020, Estonia suffered heavy losses; more than 65 tons of rainbow trout died and were destroyed during the IHN outbreak with a mortality rate of 71%. This was the first IHN case in this country. The aggravation of the epidemic situation at Estonian fish farms poses a threat to the northwestern regions of the Russian Federation, where aquaculture is practiced (the Leningrad Oblast and the Republic of Karelia). In 2022, IHN outbreaks were reported in France, Italy, Finland, Germany, Denmark and Macedonia. IHN-caused deaths were reported at the river trout farm in Georgia in 2023 for the first time. The domestic aquaculture depends on the import of eggs and seed material from Norway, Denmark, Finland and other countries, therefore a regular disease monitoring is urgently needed. The paper provides a brief description of the IHN causative agent, describes its epidemiology, pathogenesis, clinical signs, post-mortem lesions, diagnostic tests, infection control and prevention measures. We have reviewed 88 literature sources to summarize the information.

Keywords: review, infectious hematopoietic necrosis virus, fish diseases, disease situation

Acknowledgements: The study was funded by the Federal Centre for Animal Health within the research topic "Veterinary Welfare".

For citation: Balakhnina K. A., Melnikov V. P. Infectious hematopoietic necrosis (review). *Veterinary Science Today.* 2024; 13 (2): 124–135. https://doi.org/10.29326/2304-196X-2024-13-2-124-135

Conflict of interests: The authors declare no conflict of interests.

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УДК 619:616-002.4:639.371.1:616-036.22(048)

Инфекционный некроз гемопоэтической ткани лососевых рыб (обзор)

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РЕЗЮМЕ
Производство аквакультуры на территории Российской Федерации является неотъемлемой частью сельскохозяйственного сектора экономики страны. Страны с высоким уровнем и темпами развития аквакультуры (Норвегия, США, Китай, Япония, Канада и др.) и растущей эффективностью производства рыб являются центрами возникновения и распространения инфекционных заболеваний, которые при ненадлежащем контроле проникают на территорию других государств и распространяются в новых ареалах, угрожая в том числе и отечественной отрасли. В последние годы значительный ущерб рыбоводным хозяйствам наносит инфекционный некроз гемопоэтической ткани лососевых рыб. В 2020 г. большие потери понесла Эстония, где во время вспышки данного инфекционного заболевания погибло и было уничтожено более 65 тонн радужной форели, показатель смертности при этом составил 71%. Это был первый случай инфекционного некроза гемопоэтической ткани в этой стране. Обострение эпизоотической ситуации на рыбоводческих предприятиях Эстонии представляет угрозу северо-западным регионам Российской Федерации с развитой аквакультурой (в Ленинградской области и Республике Карелии). В 2022 г. вспышки инфекционного некроза гемопоэтической ткани отмечали во Франции, Италии, Финляндии, Германии, Дании и Македонии. А в 2023 г. впервые в Грузии отмечена гибель рыб от данного заболевания на речной форелевой ферме. Отечественное производство продукции аквакультуры зависит от импорта икры и посадочного материала из Норвегии, Дании, Финляндии и других стран, поэтому возникает необходимость в регулярном эпизоотологическом мониторинге. В статье дана краткая характеристика возбудителя инфекционного некроза гемопоэтической ткани, описаны эпизоотология, патогенез, клинические признаки, патолого-анатомические изменения, методы диагностики, профилактики и меры борьбы с инфекцией. Обзор составлен на основе анализа 88 источников.

Ключевые слова: обзор, вирус инфекционного некроза гемопоэтической ткани, болезни рыб, эпизоотическая ситуация

Благодарности: Работа выполнена за счет средств ФГБУ «ВНИИЗЖ» в рамках тематики научно-исследовательских работ «Ветеринарное благополучие».

Для цитирования: Балахнина К. А., Мельников В. П. Инфекционный некроз гемопоэтической ткани лососевых рыб (обзор). *Ветеринария сегодня*. 2024; 13 (2): 124–135. https://doi.org/10.29326/2304-196X-2024-13-2-124-135

Конфликт интересов: Авторы заявляют об отсутствии конфликта интересов.

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INTRODUCTION

Infectious hematopoietic necrosis (IHN) is a highly contagious viral disease of salmonid species, occurring in freshwater and marine fish and characterized by high mortality, decreased fish production levels and deformities that occur in the survivors. The disease may be referred to by a number of other names such as sockeye salmon viral disease, Columbia River sockeye disease, Oregon sockeye disease and Sacramento River Chinook disease. However, currently the generally accepted name of the disease is infectious hematopoietic necrosis. IHN is included into the list of dangerous and economically significant diseases, notifiable to the World Organization for Animal Health (WOAH) [1]. A wide range of salmonid species, both farmed and wild, are susceptible to the disease. Juveniles up to 2–6 months of age are most susceptible. The disease of the majority of the juveniles causes significant damage and losses, thus posing threat of complete ruin of the farmer. The disease is characterized by a high mortality rate (90–100%), loss of productivity and fish production efficiency and impaired fish quality and commodity size. Both freshwater and marine aquacultured fish manifest the disease. The disease outbreaks in the countries, where aquaculture is well-developed, cause significant economic damage [2, 3, 4].

PATHOGEN CHARACTERISTICS

The IHN causative agent is an RNA-containing virus of the *Rhabdoviridae* family from the *Novirhabdovirus* genus, which was isolated into a separate taxon by the International Committee on Taxonomy of Viruses in 2014[1]. The novirhabdoviruses were classified as a separate taxon due to the presence of the NV gene, which is the major difference from vesiculoviruses [5]. The virion is a bullet-shaped spiral nucleocapsid, approximately 110 nm long and 70 nm in diameter (Fig. 1) [6, 7]. There is only one serotype of the virus. Both low-virulent and high-virulent viruses are reported among field isolates. IHNV is isolated and cultured in continuous cell lines EPC, AS, BF-2, CHSE-214, FHM, ICO, RTH-149, RTG-2 and STE-137 [8, 9, 10, 11, 12, 13].

The IHNV genome is a non-segmented, negative-sense, single-stranded RNA genome of approximately 11,000 nucleotides. The viral genome codes six proteins in the following order: a nucleoprotein (N), a phosphoprotein (P), a matrix protein (M), a glycoprotein (G), a non-virion protein (NV), and a polymerase (L) [14, 15, 16, 17, 18, 19].

The inner helical ribonucleocapsid core consists of the ribonuclease genome and N, M and L proteins. The matrix protein (M) attaches to both the G protein on the internal side of the membrane and to the ribonucleocapsid. The outer membrane consists of a lipid bilayer membrane and the glycoprotein (G) that projects externally and forms noncovalently bound homotrimer spikes [19, 20, 21, 22].

The N protein of IHNV contains 413 amino acids and has a molecular mass of 40.5–44.0 kDa. This is the earliest expressed and most abundant protein produced by the virus during an IHNV infection. The P protein, previously called the M1 protein, contains 231 amino acids and has a molecular mass of 25.6 kDa. The M protein, previously called the M2 protein, is a highly basic protein. It contains a number of basic amino acids at the N-terminal end that are conserved among the homologous matrix proteins of other fish rhabdoviruses. The G protein with a molecular mass of 67–70 kDa contains 508 amino acid residues and forms the spike-like projections on the surface of the mature virion. This protein binds to cell receptors and is responsible for the attachment of the virus to the membrane of the host cell, cell fusion, syncytia formation and typical cytopathic effect. The G protein is also the target of neutralizing antibodies [23]. The L encodes a protein of 1986 amino acids with a predicted molecular weight of approximately 225 kDa and shows similarity to the RNA-dependent RNA polymerase genes of other rhabdoviruses. The NV gene was discovered first in IHNV between the G and L genes

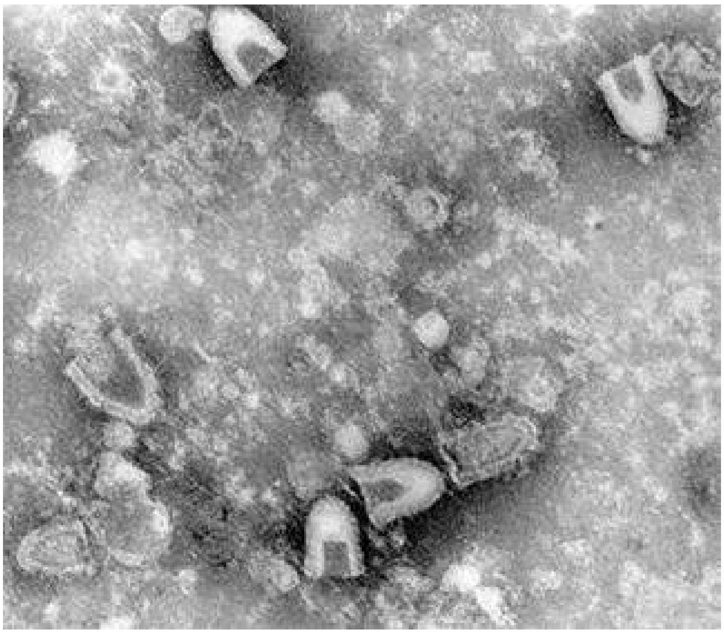

Fig. 1. IHNV viewed under an electron microscope [7]

[1] International Committee on Taxonomy of Viruses (ICTV). https://ictv.global/taxonomy

and subsequently in other aquatic rhabdoviruses such as viral hemorrhagic septicemia virus, Hirame novirhabdovirus, snakehead rhabdovirus, and various eel viruses [24, 25]. The NV gene encodes a nonstructural protein, which can be identified within infected cells but not in purified virions. This protein is required for efficient replication of IHNV *in vivo* [25].

G gene sequencing of North American IHNV isolates has revealed 3 major genogroups, designated U, M and L [26, 27, 28]. Representatives of these genogroups circulate in certain geographically isolated populations of wild salmonids. The U genotype group isolates are most spread in Alaska and British Columbia, and watersheds of coastal Washington and the Columbia River basin in Washington, Oregon and Idaho states. The M group contains isolates from Idaho, the Columbia and Snake River basins, and a virus from the Washington coast. The L genotype contains most of the viruses from California and the southern Oregon coast. Molecular genetic methods confirmed that IHNV European and Asian isolates are of North American origin [29, 30, 31]. Tests have shown that different viral genogroups are species-specific. For example, IHNV genogroup U isolates have been shown to have higher virulence in sockeye salmon, whereas genogroup M viral isolates cause a significantly lower mortality in sockeye salmon. However, genogroup M viruses are highly pathogenic for rainbow trout, though low mortality rate is reported in case of infection with genogroup U viruses [32]. Genogroup L viruses are most virulent in chinook salmon [33].

EPIDEMIOLOGY

Resistance to physicochemical factors and disinfection. IHNV survives in fresh water at 15 °C for 1 month, especially if organic material is present. IHNV is heat, acid and ether labile; readily inactivated by common disinfectants and drying. The virus is not resistant to high temperatures and is almost completely inactivated in 15 minutes at 45 °C, and completely destroyed at 60 °C [34].

Susceptible host species. Fry is the most highly susceptible age group. Fish become increasingly resistant to infection with age until spawning, when they once again become highly susceptible.

There is a high degree of variation in susceptibility to infection with different IHNV strains; the same viral strain can cause infection of different intensity in different fish species.

A wide range of salmonids are susceptible to the virus, including Arctic char (*Salvelinus alpinus*), Atlantic salmon (*Salmo salar*), brook trout (*Salvelinus fontinalis*), whitespotted char (*Salvelinus leucomaenis*), brown trout (*Salmo trutta*), chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*Oncorhynchus keta*), coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Oncorhynchus clarkii*), lake trout (*Salvelinus namaycush*), masu salmon (*Oncorhynchus masou*), marbled trout (*Salmo marmoratus*), rainbow trout (*Oncorhynchus mykiss*), mountain whitefish (*Prosopium williamsoni*) and sockeye salmon (*Oncorhynchus nerka*). The most susceptible to the disease are rainbow trout, chinook salmon, sockeye salmon and chum salmon. Sockeye salmon juveniles are highly susceptible IHNV [1, 11, 35, 36].

It is believed that white sturgeon (*Acipenser transmontanus*), European eel (*Anguilla anguilla*), tube-snout (*Aulorhynchus flavidus*), Pacific herring (*Clupea pallasii*), Shiner perch (*Cymatogaster aggregate*), turbot (*Scophthalmus maximus*), burbot (*Lota lota*), Arctic grayling (*Thymallus arcticus*), American yellow perch (*Perca flavescens*) and all varieties and species of common carp (*Cyprinus carpio*) [2], are also susceptible to the disease, but there is not enough evidence to confirm this fact. Despite the fact that these species are less susceptible to IHNV, they can serve as a natural reservoir of infection [37, 38, 39].

Geographical distribution. IHNV was first detected in fish farms on the North American west coast in the 1940s [9]. Historically, the geographical range of this pathogen was limited to the western (Pacific) part of North America in the territories of the USA and Canada, where IHN is endemic among populations of wild salmonids [7, 10, 34].

However, the disease was introduced to Europe and Asia with exported infected fish and eggs in the late 1980s. Currently, the disease is spread all over the world, including Japan, South Korea, Chile, China, Taiwan, Turkey and many European Union countries [14, 40, 41, 42, 43, 44].

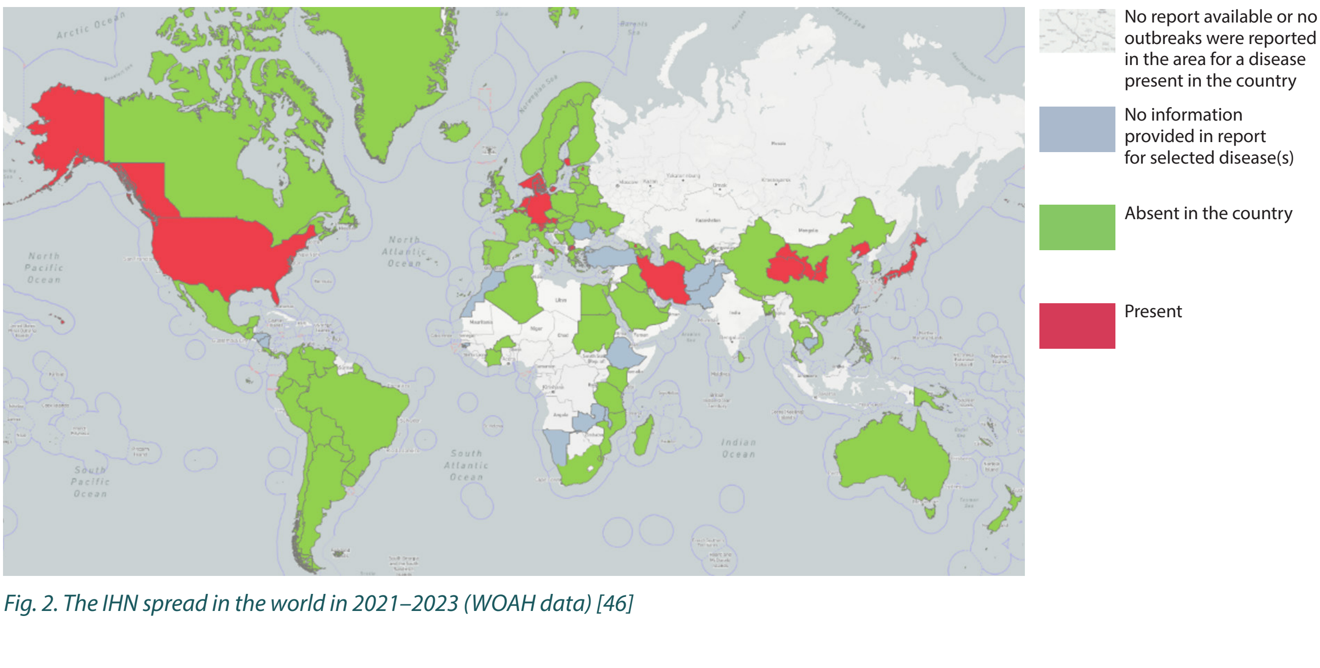

Fig. 2. The IHN spread in the world in 2021–2023 (WOAH data) [46]

Fig. 3. Salmon louse (Lepeophtheirus salmonis) on Atlantic salmon (photo made by the staff of the Reference Laboratory for Aquaculture Diseases, FGBI "ARRIAH")

In Russia, the IHNV virus was isolated in the Krasnodar Krai and the Republic of Karelia [45].

From 2021 to 2023 IHNV outbreaks were reported in Estonia, Denmark, Finland, Germany, France and Italy (Fig. 2).

In 2023, IHN-induced deaths of fish were reported at a river trout farm near Gori in Georgia. By July 12, 2023, 1.1 thousand fish died and 1.5 thousand fish were emergently killed out of 40 thousand on the farm.

Transmission mechanism. The source of infection is diseased fish, virus carriers and freshly dead fish. IHNV enters the body through the gill, damaged skin, fins and oral/gastrointestinal tract. The transmission of IHNV between fish is primarily horizontal and high levels of virus are shed from infected juvenile fish. During spawning fish become highly susceptible to the infection and may shed large amounts of virus in sexual products. Cases of vertical or egg-associated transmission have been recorded. Although egg-associated transmission is significantly reduced by the now common practice of surface disinfection of eggs with an iodophor solution [47]. The virus is transmitted from fish to fish by direct contact, through water, silt, and fish handling equipment. An oral route of transmission is possible through cannibalism and feeding on infected fish. Unauthorized movement of eggs and fish from infected farms also contributes to the viral spread [9, 48]. Once IHNV is introduced into a farmed stock, the disease may become established among susceptible species of wild fish in the watershed. The length that individual fish are infected with IHNV varies with temperature. Survivors of infection with IHNV demonstrate a strong protective immunity with the synthesis of circulating antibodies to the virus [49]. Reservoirs of IHNV are clinically infected fish and covert carriers among cultured or wild fish but a true, life-long IHNV carrier state appears to be a rare event. Virus is shed via urine, sexual fluids and from external mucus (more seldom with feces), through gills, skin and fins [9, 37, 38, 50].

Vectors. Invertebrate vectors have been proposed to play a role in IHNV transmission. Blood-sucking parasites (leeches, copepodes) as well as some piscivorous birds are potential vectors for IHNV [50].

Study by E. Jakob et al. [51] showed that the salmon louse (*Lepeophtheirus salmonis*) (Fig. 3) is capable of IHNV transmitting under laboratory conditions. Although salmon lice are often considered not to transfer between hosts, such transfers have been observed under farmed and laboratory conditions, particularly when the host fish were kept at high densities [52]. Lice that were exposed to IHNV in water or had parasitized experimentally infected Atlantic salmon were put in different tanks containing naive Atlantic salmon. Mortalities of 70.6 and 66.6% respectively were observed in the two tanks of fish respectively in 7–9 days. IHNV was recovered from the majority of exposed fish. The authors concluded that under the experimental conditions the lice are mechanical vectors [51].

IHNV was isolated from adult Mayflies (*Callibaetis* sp.) collected from streams and an abandoned fish hatchery on a number of occasions [53].

A wide range of farmed fish from freshwater and the northern European marine environment, and to a much lesser degree farmed marine Mediterranean fish, are considered possible vectors of IHNV. Furthermore, there is evidence for the potential of IHNV transmission via invertebrates and piscivorous birds, and other animals may play a role.

Cyprinidae and other freshwater fish, marine fish and freshwater crustaceans are judged to be potential vectors of IHNV [54].

Mortality and morbidity. Depending on the species of fish, farming conditions, temperature, and, to some extent, the virus strain, outbreaks of infection with IHNV may range from explosive to chronic. Losses in acute outbreaks will exceed several per cent of the population per day and cumulative mortality may reach 90–95% or more [50]. In chronic cases, clinical signs are less pronounced, losses are protracted and fish in various stages of disease can be observed in the pond.

Larvae may die immediately after hatching and mortality rate may be up to 80–90%. Adults are more resistant and mortality rate among yearlings is most often 20–30%. Infection with IHNV can produce mortality in water temperatures from 3 to 18 °C. In Alaska, the disease can cause up to 100% mortality in sockeye salmon at water temperatures as low as 1–2 °C [55].

Disease factors. Older fish are typically more resistant to clinical disease. But among individuals, there is a high

Fig. 4. Rainbow trout fry. IHNV infected fish (left) shows darker coloring [61]

Fig. 5. Cephalic bumps on sockeye salmon fry, characteristic of IHN disease [55]

degree of variation in susceptibility to infection with IHNV. Good fish health condition seems to decrease susceptibility to overt infection with IHNV, while co-infections with bacterial diseases (e.g. bacterial coldwater disease), handling and other stressors can cause subclinical infections to become overt.

The most important environmental factor affecting the progress of infection with IHNV is water temperature. In natural conditions, the disease occurs at water temperatures of 3 to 15 °C and morbidity decreases with the water temperature increase. IHNV epizootics usually occur during spring season (end of winter – beginning of summer) and less often during autumn season (end of summer and autumn), but if the temperature is suitable, the outbreaks can be observed at any time of the year. The disease is most acute at 10–12 °C. Up to 80–100% of juveniles may die [11]. In 100–500 g fish, the disease, as a rule, proceeds in a chronic form and mortality rate does not exceed 10–25%. The younger the fish is, the more it is susceptible to the virus even at higher temperatures. This is associated with the immature immunity in fry.

IHN outbreak may not occur even if the virus circulates in the fish population. The disease in fish is provoked by stressful conditions caused by handling and rearing violations (transportation, sorting, temperature fluctuations, low oxygen levels, sudden pH changes, metabolite accumulation in water, etc.) [9, 56].

PATHOGENESIS

The incubation period in case of natural infection in fingerlings at a water temperature of 10–15 °C is about 7–12 days [57].

Virus entry is thought to occur through the gills, skin, fins and anterior gastrointestinal track. Harmache A. et al. proved that that the fin bases are the major portal of entry for IHNV in 2006 [58]. IHNV exhibits a specific tissue tropism for connective tissue while splenic and renal hematopoietic tissues are the first and most severely affected areas. These organs are the sites in which virus is most abundant during the course of overt infection [34, 50].

Virus multiplication in endothelial cells of blood capillaries, hematopoietic tissues, and cells of the kidney underlies the clinical signs. Impairment of osmotic balance makes plasma release from blood cells into the interstitial space and body cavity, and occurs within a clinical context of oedema and haemorrhage [59]. The disease can progress to a lethal necrosis of the hematopoietic tissues of the kidney and spleen, a generalized viraemia with associated necrosis in all tissues. Death is due to renal failure caused by electrolyte imbalance [60].

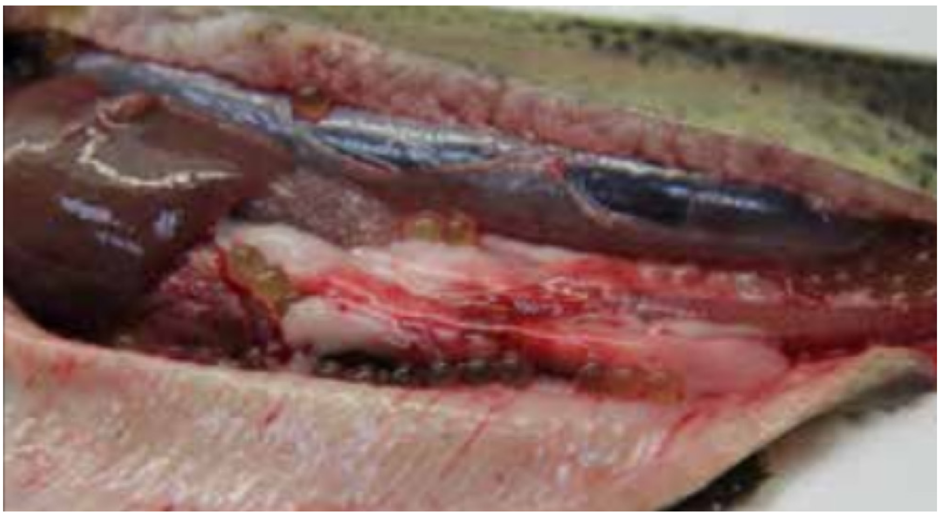

Fig. 6. Haemorrhages on the swim bladder, intestine and fat tissue of IHNV infected fish [63]

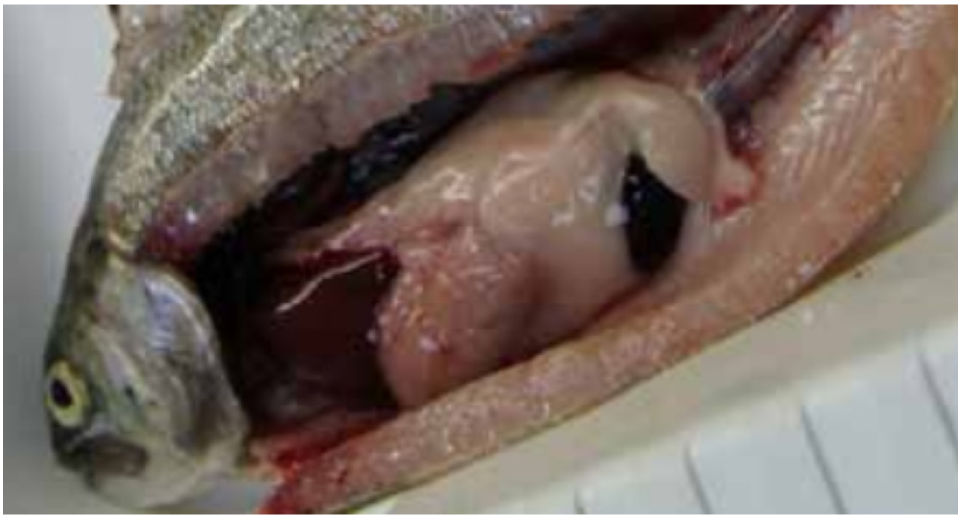

Fig. 7. Spleenomegaly in IHNV infected fish [63]

PATHOLOGY

The disease is characterized by sepsis, severe affection of hematopoetic organs, hemorrhages in organs and tissues.

First clinical signs of classical (acute) IHNV infection in 0.2–8.0 g fry are: anorexia and depression, lethargy. Other symptoms include darkening of the skin (Fig. 4), laying on the bottom or hanging around the water surface and swimming along the sides of the tank to avoid the currents.

In acute disease there is a sudden increase in fish mortality, but the fish may not show clinical signs and may die without apparent cause [62]. During outbreaks, fish are typically lethargic with bouts of frenzied, abnormal activity (spiral swimming, whirling and flashing), dark coloration, exophthalmia, pale gills, petechial hemorrhages around the eyes and fins, less often on the abdomen and behind the head, ascites (distended abdomen). Some affected fish show trailing faecal casts (of grey color, sometimes with blood). The larvae demonstrate multiple hemorrhages in the yolk sac and characteristic cephalic bumps on the head (Fig. 5). The fry exhibit hemorrhages at the base of the fins and on the mucous membranes, as well as in the yolk sac.

A post-mortem examination reveals the accumulation of a watery, yellowish (sometimes bloody) fluid and there may be petechial haemorrhages in the visceral mesenteries, adipose tissue, musculature, peritoneum, intestine and swim-bladder (Fig. 6). Necrotic changes and hemorrhages are observed in the kidneys and liver. The spleen is pale. The liver, kidneys and spleen are enlarged (Fig. 7). Fish may have empty stomachs, intestines filled with yellowish bloody mucus [59, 62].

In some fish over 8 g, usually at the final stage of the epizootic, a nervous form of the disease develops, manifested by behavior changes (periods of hyperactivity and depression). Usually there are no clinical signs, with the exception of a darker coloration, in such fish. This IHN form is due to damaged central nervous system, that's why the virus in such fish can only be detected in the brain. It is assumed that the virus concentrates in the central nervous system, where immune surveillance is less effective, replicates to about 10^6 PFU/g and destroys brain tissue, resulting in spinal deformities – scoliosis (Fig. 8) of 1–5% of survivors.

The third form of IHN is epitheliotropic, or gill targeting, is observed in older fish of about 50–100 g of weight. Large fish can become infected with the IHNV, but the infection does not become systemic due to the age of the fish or any other factor. However, the agent replicates very effectively in the epithelial cells of the fins, skin and gills and can cause serious breathing problems due to anemia, often hemorrhages in the gills (Fig. 9). Mortality is sporadic, but due to the fact that larger fish are affected, losses (in the total weight of the product) can be high. This ultimately reduces the economic efficiency of the fish farm (decreased weight gain and increased feed conversion) [64, 65].

Diseased fish usually demonstrate some of the above mentioned signs. Only a few affected fish can exhibit all characteristic clinical signs and gross internal lesions during the epizootic. None of the signs described are considered to be pathognomonic for the disease. The blood of affected fry shows reduced haematocrit, leukopenia, degeneration of leucocytes and thrombocytes, and large amounts of cellular debris. As with other haemorrhagic viraemias of fish, blood chemistry is altered in severe cases.

Histopathological findings reveal degenerative necrosis in hematopoietic tissues, kidney, spleen, liver, pancreas, and digestive tract. Necrosis of eosinophilic granular cells in the intestinal wall is pathognomonic of IHNV infection [50].

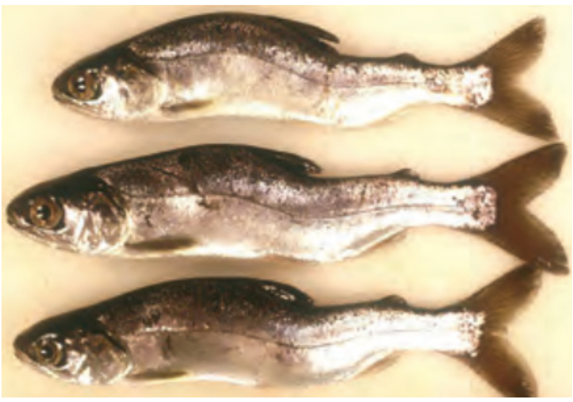

Fig. 8. Scoliosis in sockeye salmon smolts surviving IHNV infection [55]

Fig. 9. Anemia and hemorrhages in the gills of IHNV-infected fish [63]

DIAGNOSIS

A preliminary diagnosis should be based on the epidemiological data, clinical appearance of the disease and post mortem findings. The final diagnosis should be based on the results of the virological examination, including isolation and serological identification of the virus, and, if necessary, a bioassay [9, 13, 39, 62].

The optimal tissue material to be examined is spleen, anterior kidney, and heart or encephalon. In some cases, ovarian fluid and milt must be examined.

The "Gold Standard" for detection of IHNV is the isolation of the virus in cell culture followed by its immunological or molecular identification.

Various continuous fish cell lines are used to isolate the virus: EPC, AS, BF-2, CHSE-214, FHM, ICO, RTH-149, RTG-2 and STE-137 [8, 9, 10, 11, 12, 13]. The cytopathic effect in cell culture can be observed 48–72 hours post inoculation (Fig. 10).

Serological identification of the IHNV is performed using enzyme-linked immunosorbent assay (ELISA), indirect fluorescent antibody (IFA) test and neutralization test (NT). The ELISA advantages are high diagnostic sensitivity and specificity, it is less laborious and time-consuming [2, 12, 13, 59, 67, 68, 69, 70, 71]. Molecular genetic diagnostic tests are most rapid and sensitive among all IHNV detection methods. These include reverse transcription polymerase chain reaction (RT-PCR) and real-time RT-PCR using primers targeting G and N genes to detect viral RNA [13, 72, 73, 74, 75, 76, 77, 78, 79].

PREVENTION AND CONTROL MEASURES

Since there is no treatment against IHN to date and there are no commercially available vaccines on the market of the Russian Federation, the main strategy for the disease control is to ensure biosafety and to culture genetically resistant fish.

The IHN prevention shall rely on the avoidance of the disease introduction and spread in free farms, through the implementation of strict control policies and sound hygiene practices, compliance with fish farming standards to exclude or minimize the risk of IHNV introduction into fish farms [9, 37, 38, 39].

Eggs and fish seed materials shall be supplied from farms free from infectious diseases, including infectious

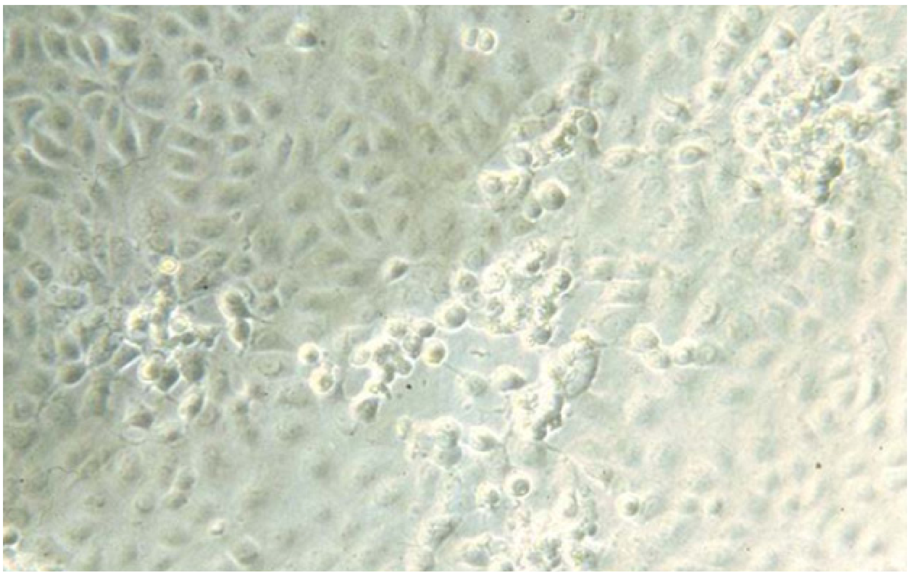

Fig.10. Cytopathic effect (CPE) on CHSE-214 cell line 72 hours post-inoculation [66]

hematopoetic necrosis. Optimal ecological and hygienic conditions shall be established in fry rearing tanks. Feeds shall contain only high-quality virus-free raw materials [37].

The seed material and eggs of a new batch shall be isolated and kept in separate ponds or tanks. Disinfection of eggs is a common practice to effectively mitigate egg-associated transmission of IHNV in aquaculture practice. The method is widely practiced in areas where the virus is endemic [80, 81, 82, 83].

In case of IHN outbreak, the farm shall be recognized disease-infected and subjected to quarantine restrictions (according to the order of the Russian Federation Ministry of Agriculture No. 173 of September 29, 2005 on approval of the list of quarantinable and highly dangerous fish diseases). All diseased fish shall be destroyed. Fish tanks and water supply channels shall be disinfected with chlorine or lime. The handling tools shall be treated with formalin, and the low-value tools shall be destroyed. If no IHN clinical signs are observed in fish during the year, and the results of virological examinations are negative, the quarantine can be lifted [37, 62].

Another control strategy is the farming of virus-resistant populations. Within endemic areas, the use of less susceptible species (chinook salmon, brook trout, cutthroat trout, brown trout, etc.) has been used to reduce the impact of infection with IHNV in aquaculture.

Experimental trials of triploid or inter-species hybrids have shown promise and the genetic basis of resistance to IHNV has been an active area of recent research [84, 85, 86].

Experimental vaccines to protect salmonids against infection with IHNV have been the subject of research for more than 50 years. Research on genetically engineered (recombinant) vaccines against IHN is undertaken in the USA, Germany and Canada [87, 88].

CONCLUSION

Infectious hematopoietic necrosis is a highly contagious disease, classified by the WOAH as a dangerous and economically significant notifiable diseases. This disease can infect a wide range of salmonids and is characterized by high mortality rates (up to 100%) and impaired fish quality and commodity size.

The situation analysis demonstrates that IHNV is the cause of frequent outbreaks in countries where aquaculture is practiced, inflicting significant economic losses. The global epizootic situation remains complicated, especially in the countries bordering the Russian Federation. Prevention is the only way to control the disease.

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Received 25.12.2023
Revised 14.02.2024
Accepted 13.03.2024

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Contribution: Balakhnina K. A. – selection and analysis of scientific literature on the topic, data interpretation, text preparation; Melnikov V. P. – data analysis, data visualization, text preparation.

Вклад авторов: Балахнина К. А. – подбор и анализ научной литературы по заявленной проблеме, интерпретация данных, подготовка текста; Мельников В. П. – анализ данных, концепция представления материалов, подготовка текста.