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Review Article

A knowledge update on current strategies on the prevention and control of rabies in Ethiopia

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Abstract

Rabies remains a major viral anthropozoonosis of public health importance. Although canine rabies has been successfully eliminated in certain regions, the disease continues to cause tens of thousands of human fatalities globally each year. Rabies imposes a considerable burden on public health and veterinary sectors; therefore, it should be prioritized at national and regional levels. In most of Africa and Asia, domestic dogs act as the primary reservoir and the major sources of human infections. Achieving adequate vaccination coverage within dog populations is crucial, as it can lead to the elimination of canine rabies in most endemic areas. Strengthening local capacities for rabies surveillance and diagnostics is essential for assessing the control and elimination initiatives. Furthermore, sustainable dog vaccination campaigns can be supported through intersectoral financing mechanisms that engage both sectors. Overall, significant technical or logistical barriers to the control of canine rabies are largely absent in most regions, and mass vaccination of domestic dogs remains a feasible and cost-effective strategy for preventing both human and animal rabies-related deaths.

Keywords: Dog-mediated rabies, Post-exposure prophylaxis (PEP), Public health, Rabies elimination, Zoonosis.

HIGHLIGHTS

- Rabies causes thousands of deaths yearly, mainly in Africa and Asia, with dogs as the main source
- Canine rabies can be eliminated through mass dog vaccination, greatly reducing human cases
- Strengthening surveillance and diagnostics is vital for effective rabies control and elimination
- Effective and sustainable dog vaccination needs joint funding and collaboration between health and veterinary sectors
- Rabies transmission from reservoirs can be reduced by separating domestic animals from wildlife and educating the public on precautions

INTRODUCTION

Rabies is among the most neglected tropical diseases and the most lethal viral zoonosis, with bats as reservoirs, causing fatal encephalomyelitis in humans and terrestrial mammals across various categories, including pets, livestock, stray animals, and wildlife (Pal *et al*., 2024; Rebuma and Mehdipour, 2024). Dogs are the main source of human rabies, especially in tropical, developing regions with limited access to prevention and treatment. Controlling rabies in dogs is key to reducing human cases (Pal, 2007). Among potential vectors, the domestic dog remains the most significant source of human rabies infections. Annual reports of the Ethiopian Health and Nutrition Research Institute (EHNRI) indicated a total of 488 human deaths that occurred in Ethiopia in 1964 and 1975 (Oyda and Megersa, 2017). Whereas, in India, recent reports state around 749 cases and 3 deaths in Manipur alone since January 2025 to April, 2025(NDTV, 2025).

Rabies can be eradicated if70% of the dog population is vaccinated repeatedly to achieve herd immunity based on empirical observation and models of the transmission of canine rabies (Sambo *et al*., 2022). Stray and free-roaming dogs, often unreachable by standard vaccination, hinder rabies control. Oral vaccines offer promise but remain largely unavailable in endemic areas. The WHO discourages dog culling due to its negative impact on herd immunity and public acceptance, emphasizing the need for humane, community-based solutions (Deressa *et al*., 2010).

In Ethiopia, domestic dogs are the principal

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reservoir of rabies (Digafe, 2015). Rabies remains a major public health threat in Ethiopia, for many centuries. The country reports an estimated 2,700 human deaths annually which is one of the highest global tolls, with incidence rates up to 4.19 cases per 100,000 people in some regions (Regassa *et al*., 2025). According to Richard Pankhurst, the first and only recorded case of rabies in Addis Ababa occurred in August 1903. In Ethiopia, the incidence rates of human post-exposure prophylaxis (PEP) and human rabies cases were reported as 73.6 and 12.6 per million population, respectively, highlighting the significant public health burden posed by rabies (Kabeta *et al*., 2014). The disease remains a critical concern that necessitates the development and implementation of effective intervention strategies. In 1998, Ethiopia recorded the highest number of human rabies-related deaths in Africa, with 43 fatalities reported (Kabeta *et al*., 2014).

The annual mass vaccination coverage is limited due to various factors. In 1997, the average anti-rabies vaccine production for animal use was about 8000 doses per year, below the domestic consumption demand. In Amhara, the dog-to-human ratio is 1:48.5, with only 16% vaccinated and 91% unneutered. Most dogs are used for guarding or herding. National data on dog populations are limited, but studies indicate high risks due to large stray populations and poor confinement, with 57% of dogs roaming freely (Adnie *et al*., 2025). In Addis Ababa, the dog population is estimated at 150,000-200,000, with approximately 50% being household dogs and the remainder consisting of stray or free-roaming owned dogs. A significant proportion of these are unvaccinated, posing a high risk for rabies transmission (Deressa *et al*., 2010). In many remote areas of Ethiopia, dogs are primarily kept for hunting and property protection, often with limited access to vaccination and veterinary care. The objective of this paper is to provide an overview of the general characteristics of the rabies virus, to explore the mechanisms for its control and prevention, and to assess its impact on both human and animal health.

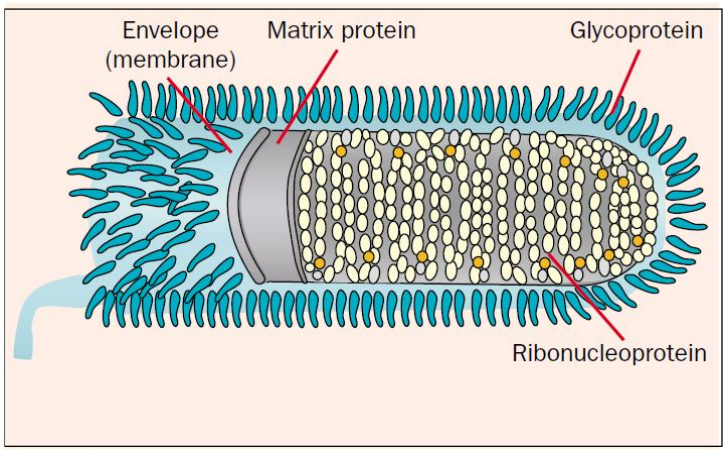

Fig. 1. A typical bulleted lyssavirus showing genome and viral antigens (Rupprecht *et al*., 2002)

Rabies Virus

Etiology: In Latin, Rabies is a word for madness. It is caused by *Rhabdovirus* (Greek rhabd=rod), a bullet-shaped RNA virus (Fig.1). Rabies virus belongs to the genus *Lyssavirus* (Greek lyssa=madness) and family of *Rhabdoviridae* (Pal, 2007). Rabies virus is a large, highly neurotropic virus that is relatively fragile and sensitive to standard disinfectants. The genus includes at least six genotypes. Early studies distinguished the naturally occurring 'street' virus from 'fixed' strains adapted for vaccine production through cell culture or serial passage in laboratory animals. It is now known that there are several strains of rabies virus, which are adapted to particular host species but remain infective for any warm-blooded mammal (Bilal, 2021).

Mode of transmission: Rabies is most commonly transmitted through the saliva of an infected animal, typically via a bite or scratch. In rare instances, transmission can occur through contact with a fresh wound or intact mucous membranes (Pal, 2007). While human-to-human transmission is extremely uncommon, it has been reported in cases involving organ or tissue transplantation. Additionally, exposure of broken skin or mucous membranes to infectious materials such as saliva or neural tissue can also lead to infection. Airborne transmission, though rare, has been documented under specific conditions, such as in laboratory environments and bat-infested caves (Pal, 2007). However, ingestion of raw meat or tissues from rabid animals is not considered a known route of human infection (WHO, 2010). Not all bites from rabid animals result in transmission of infection, as the rabies virus is not consistently present in the animal's saliva and may fail to enter the wound, particularly if the saliva is removed by clothing or the animal's fur. Rabies is rarely transmitted through milk; however, a recent fatal case in Delhi NCR, reportedly linked to raw milk from an infected cow, emphasizes the critical need to boil milk before

consumption as a preventive measure (Times of India, 2025). Airborne transmission of rabies was investigated after cases in caves inhabited by rabid insectivorous bats. Although bites remain the primary mode of transmission, inhalation can lead to infection under certain environmental conditions (Ali, 2022). A recent study provided practical evidence that rabies viral RNA can be detected in the milk of lactating animals, shedding light on an underexplored route of viral transmission (Dandale *et al*., 2014).

Pathogenesis: Rabies virus gains entry into a new host by introduction of virus-containing saliva into a bite wound (Pal, 2007). Entry may also be gained by saliva contamination of the mucous membranes of the mouth, eyes and nasal passages. Local viral proliferation in non-neural tissue takes place at the entry site, followed by viral attachment to nerve cell receptors and peripheral nerve endings. After entering through peripheral nerves, the rabies virus travels via afferent axons to the central nervous system, where it replicates and spreads throughout the brain and spinal cord (Fig. 2). It then moves centrifugally along efferent nerves to reach the salivary glands, enabling transmission through saliva. The resulting brain infection alters behavior, promoting biting and further spread. Rabies is almost always fatal once CNS infection occurs, typically due to respiratory paralysis, though secondary complications may also contribute. The rabies virus exhibits a marked tropism for spinal motor neurons, leading to inflammation and demyelination predominantly in the anterior horn of the spinal cord. A 2025 case study documented T2-weighted hyper intense lesions in the dorsal gray matter, which were clinically associated with acute flaccid paralysis and impaired bladder function (Varaprasadvarma *et al*., 2025). Gradually ascending paralysis with severe signs of mania, which persist almost until death. Destruction of spinal neurons results in paralysis, but when the virus invades the brain, irritation of higher centers produces manias, excitement, and convulsions (Potratz *et al*., 2020).

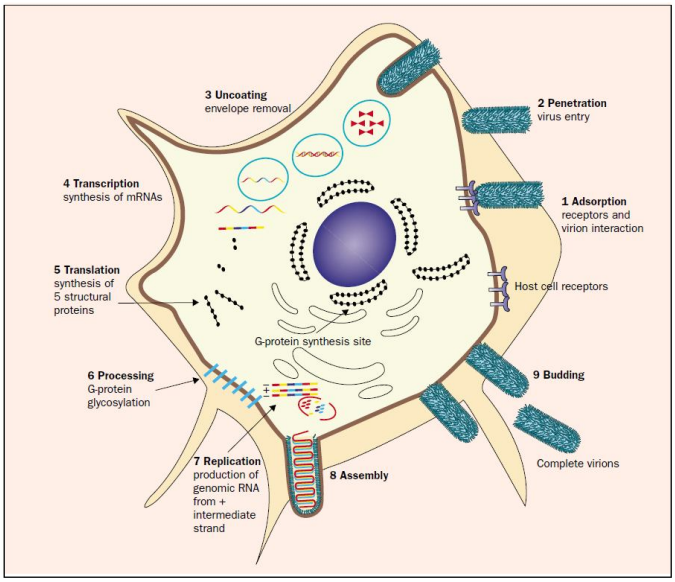

Fig. 2. Pathways of lyssavirus showing reception, entry, transcription, translation, replication, and exit from a generalised host cell (Rupprecht *et al*., 2002).

Epidemiology

Occurrence: All warm-blooded animals can contract rabies (Pal, 2007). Except isolated nations that prevent it by strict quarantine regulations or by forbidding the admission of dogs, the disease affects cattle, sheep, pigs, and horses in the majority of countries. Understanding the intricate epidemiology of animal rabies requires an awareness of the significance of the virus-host-environment connection (Yousaf *et al*, 2012).

Host susceptibility: All mammals are susceptible to infection; the degree of susceptibility may be influenced by some host factors (age, health, nutrition, etc.). A 23% increase in host activity range under warmer temperatures, along with increased human skin exposure, significantly elevates bite transmission risk (Regassa *et al*., 2025). The human immune response to the infection is usually not enough prevent disease (Carroll, 2010).

Reservoir and source: Globally, over 98% of all human rabies occurs following exposures to infected dogs. Reservoir species such as dogs and vampire bats exhibit up to 10× higher viral loads in saliva compared to non-reservoir mammals (Wallace *et al*., 2023). Monkeys are the second most frequent source of human rabies in under developed nations (Di Quinzio and McCarthy, 2008). The majority of human cases in North America during the last ten years have been linked to bat exposure (Blanton *et al*., 2012).

Clinical signs

Incubation period: Usually 20-60 days, but it varies from a few days to years. Length of incubation depends in part on wound severity, location concerning nerve supply, relative distance from the brain, the amount and variant of virus, and the degree of protection provided by clothing

and other factors. Bites in areas with rich nerve distribution (e.g., head, face, neck) have shorter incubation periods due to faster viral transport to the CNS (Mahadevan *et al*., 2016).

Signs and symptoms: Classically, rabies has been described as having a prodromal phase followed by either an excitable, furious form or a paralytic dumb form (Pal, 2007). Paralytic (or "dumb") rabies is characterized by progressive paralysis, beginning with muscles of the head and neck, leading to hyper salivation, difficulty swallowing, and changes in vocalization such as hoarse howling or aberrant bellowing. Other signs include facial paralysis, dropped jaw, ataxia, and spinal paresis, often without a preceding excitatory phase; biting is uncommon, and death typically occurs within two to six days due to respiratory failure. In contrast, the furious form-more common in cats and particularly dangerous in large animals like horses-involves infection of the limbic system, causing restlessness, excessive vocalization, polypnea, hyper salivation, unprovoked aggression, and sometimes pica, including ingestion of non-food items.

Wild animals with rabies may lose their natural fear of humans and exhibit unusual aggression, while nocturnal species may become active during the day. In cattle, heightened alertness can be an early sign. Terminal stages may involve convulsions, with death sometimes occurring during a seizure. Animals with the furious form typically die within 4 to 8 days of symptom onset, and survival in either form is exceedingly rare. Abortive rabies instances were documented in Peru, and 11% of cattle in vampire bat habitats had rabies virus neutralising antibodies; nonetheless, no deaths were noted in those animals within two years (Benavides *et al*., 2020). In rabid animals, particularly cattle, multiple individuals may show simultaneous signs such as a hoarse bellow, provoked aggression, attacks on objects or other animals, and unusual behaviors like wind-sucking or the "bone in throat" posture. Other symptoms include isolation from the herd, anorexia, knuckling of the hind fetlocks, ataxia, paralysis of the tail, limbs, jaw, and tongue, hyper salivation, dragging hooves, pseudo-oestrus, hyper sexuality, reduced milk yield, dilated pupils, fixed gaze, teeth grinding, pica, tenesmus with diarrhea, frequent urination, weight loss, and subcutaneous emphysema (Fig. 3).

Diagnosis

Since clinical diagnosis of rabies is difficult and frequently inaccurate, laboratory-based methods of confirmation are highly advised. The fluorescent antibody test (FAT) is the gold standard for post-mortem diagnosis, which involves detecting the rabies virus antigen in infected tissues, preferably brain smears or touch impressions taken by biopsy. When applied to fresh specimens, usually within a few hours, this technique yields dependable results in 95-99% of cases and is approved by the World Health Organisation (WHO, 2025). Other than the CNS, the virus might also be found in other tissues such as the salivary gland, skin (tactile facial hair follicles) and corneal impression smears, but detection is less efficient. Immunofluorescence is the most commonly used assay and is most effective on fresh samples. Mouse inoculation may still be used in some cases, but cell

Fig. 3. Knuckling fetlocks and hind-quarter paralysis in a bovine (Heymann, 2008) **and hyper salivation in dogs exhibited in paralytic form of rabies** (Rupprecht *et al*., 2002).

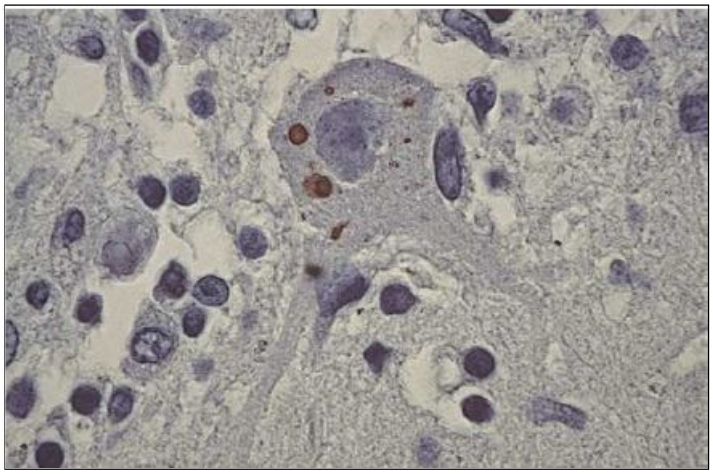

Fig. 4. In immunohistochemistry, a formalin-fixed neuron showing reddish-brown viral inclusions in the cytoplasm of rabies patients (Rupprecht *et al*., 2002).

culture is generally preferred due to higher sensitivity, faster results, and ethical considerations (Polupan and Rudoi, 2024).

Laboratory testing: Animals can only be definitively tested for rabies post-mortem, typically by euthanizing the animal, removing the head, and examining brain tissue for the presence of the virus. In contrast, ante mortem diagnostic tests are available for humans and involve the collection of multiple specimens, including serum, cerebrospinal fluid (CSF), saliva, and a skin biopsy from the nape of the neck that includes hair follicles. The recommended laboratory diagnostic protocol comprises three main tests, with the use of at least two being advised for reliable results. These include the fluorescent antibody test (FAT) on brain tissue impression smears, a dot ELISA for antigen detection in animals, and histological examination for Negri bodies in tissue sections typically yielding results within 48 hours (Garg, 2014). Historically, the hippocampus was considered a critical tissue in rabies diagnosis due to its role in the histological identification of Negri bodies. However, its diagnostic utility is now regarded as limited, particularly when brainstem and cerebellar tissues are available for examination. Fresh, unfixed brain samples are important for a rapid and accurate diagnosis of rabies. Tissue alteration by chemical fixation, such as formalin, may make a sample unsuitable for routine Direct Flourescent Antibody testing, however, the methods such as immunohistochemistry is found suitable for fixed tissue sample testing but they require specialized skills (Fig. 4) (Rupprecht *et al*., 2002). Other method for testing fixed tissue such as immunohistochemistry, require specialized training and delay test results. Molecular test such as reverse transcriptase polymerase chain reaction (RT-PCR) has been developed for rabies diagnosis. This technique is very sensitive and specific and can be easily employed for diagnosing rabies on ante mortem samples obtained from humans (Biswal *et al*., 2012).

Treatment, prevention, and control of rabies Control in humans: Once clinical signs of rabies appear, treatment is not effective and should not be pursued. The primary objective of rabies control efforts in both domestic and wild animals is to prevent human infection. The most effective strategy for reducing the incidence of human rabies is to decrease the prevalence and transmission of the disease within animal populations (Ali, 2022).

Wound management: Rabies virus enters the body through bites or scratches, making immediate wound cleansing essential. Wounds should be gently washed with soap or detergent and flushed with running water for at least 10 minutes to inactivate and remove the virus. This should be done even if the patient presents late. Direct contact with the wound should be avoided, and anti-rabies clinics must provide proper wound-washing facilities (WHO, 2018).

Rabies immunoglobulins (RIG): Anti-rabies serum or rabies immunoglobulin (RIG) provides passive immunity by neutralizing the rabies virus, preventing infection during the early phase before the body produces its own antibodies. Two types of Rabies immunoglobulins are available: Equine rabies immunoglobulins (ERIG) and Human rabies immunoglobulin (HRIG). ERIGs are of heterologous origin, derived from horses hyper-immunized against rabies. Modern ERIG preparations are highly purified, significantly reducing adverse reactions, but a sensitivity test is still recommended before administration due to possible hypersensitivity (Terryn *et al*., 2016). The side effects encountered in a serum of heterologous origin are usually absent in Human rabies immunoglobulin (HRIG)and is given in half the dose of equine anti-rabies serum due to its longer half-life (WHO, 2018).

Anti-rabies vaccines: Immunization remains the main tool for the control of several zoonotic diseases including rabies (Pal, 2007; Pal, 2017). It is pertinent

to mention that rabies vaccine can be used for pre-exposure as well as post-exposure (Pal, 2007). When administered after exposure, the rabies vaccination produces immunity in seven to ten days. If the suspected source animal is still healthy ten days after the exposure or if a laboratory confirms that a brain sample from a euthanised animal is found negative for rabies, then the vaccination can be stopped (Pal, 2007; Pal *et al*., 2024).

Table 1. Type of contact, exposure and recommended post-exposure prophylaxis (Pinto *et al*., 2019).

Category	Types of contact	Types of exposure	Recommended post-exposure prophylaxis
I	Touching or feeding of animals Licks on intact skin	None	None, if a reliable case historyis available
II	Nibbling of uncovered skin Minor scratches or abrasions without bleeding	Minor	Wound management Anti-rabies vaccine
III	Single or multiple transdermal bites or scratches, licks on broken skinContamination of the mucous membrane with saliva (i.e. licks)	Severe	Wound management Rabies immunoglobulin Anti-rabies vaccine

For previously vaccinated persons: People who previously got full post-exposure prophylaxis (by IM or ID route) with a powerful cell-culture vaccination should now only receive two booster doses if they are re-exposed, intramuscularly (0.5 mL/1mL)/ intradermally (0.1 mL at 1 site) on days 0 and 3. Proper wound toilet should be done. Treatment with RIG is not necessary. If a vaccinated person is exposed to rabies, wound toileting at two IM/ID (0.1 mL at 1 site) doses of Cell Culture Vaccine be given on days 0 and 3 should be done. Individuals who have previously undergone complete post-exposure treatment with NTV ought to be considered as new cases and may receive treatment based on the case's merits (Table 1) (NCDC, 2024; Nadal, 2020).

Preventive measures in humans

Immunization: Pre-exposure rabies vaccination is recommended for individuals at high risk, such as laboratory personnel, healthcare providers, veterinarians, wildlife handlers, quarantine officers, and travelers to rabies-endemic areas (Rupprecht *et al*., 2002; Pal, 2007; Pal *et al*., 2024). The vaccine is administered in three doses on days 0, 7, and 21 (or 28), either intramuscularly or intradermally. Those at high risk should have antibody titres checked every six months, with a booster given if titres fall below 0.5 IU/mL. Following exposure, individuals with prior vaccination need only two booster doses on days 0 and 3, without requiring rabies immunoglobulin (RIG) (Quiambao *et al*., 2022). In 2023, the WHO reaffirmed the effectiveness and cost-efficiency of the condensed 1-week intradermal rabies vaccination protocol (2-site ID on days 0, 3, and 7). This regimen has shown comparable immunogenicity to conventional intramuscular regimens and is particularly advantageous in resource-limited environments, enabling a greater number of individuals to be vaccinated with restricted vaccine availability (WHO, 2023). Despite the demonstrated efficacy of vaccines, instances of probable vaccine failure have been reported. A recent case reported from the state of Kerala, India, involved three fatalities following vaccination, prompting concerns regarding the quality control measures associated with vaccine production and distribution (The Indian Express, 2025). In some areas, reports were stating an inadequate supply of vaccines for use among the affected or at-risk population, thus posing challenges in the proper immunization protocols (NDTV, 2025).

Education: Effective prevention and prompt post-exposure intervention rely on public awareness of rabies risks from animals like bats and skunks. A notable example is Azerbaijan's public education campaign, which significantly improved knowledge of rabies symptoms, vaccination schedules, and raised canine vaccination rates key to reducing human rabies risk. Using posters, pamphlets, and SMS messages, the campaign educated the public on rabies-carrying animals and proper bite responses. While it enhanced recognition of rabies signs and preventive actions, the increase in health-seeking behavior post-exposure was minimal (Hasanov *et al*., 2018). Another example is Ethiopia's 2017 rabies elimination strategy, which focused on dog vaccination, PEP access, awareness, and surveillance. To support this, the UK Health Security Agency (UKHSA), WHO, EPHI, and the Ministry of Agriculture (MOA) conducted a training program for Animal Health Assistants (AHAs) and

Community Health Extension Workers (CHEWs). This initiative aimed to enhance joint public and veterinary surveillance systems and build capacity for rabies prevention and response at the community level (UKHSA, 2023). However, challenges remain due to imperfect awareness and variable access to PEP in many regions, underscoring the need for continuous and culturally tailored public education (Lodha *et al*., 2023).

Animal management: In enzootic regions, it is advisable to register, license, and vaccinate all dogs where feasible. Cats and ferrets should also be vaccinated against rabies. Additional preventive measures include sterilizing pets, maintaining control over them, such as using leashes particularly in unfamiliar areas or environments where encounters with other domestic or wild animals are more likely. Homeowners should identify and secure potential entry points for wildlife, such as chimneys, to prevent intrusion. If bats are found roosting within a residence, consultation with animal control or a wildlife professional is recommended (Krienitz, 2018). Individuals should avoid contact with wild or stray animals and ensure that young children are appropriately cautioned against such interactions. Handling of sick or unusually behaving domestic or wild animals should be strictly avoided. Keeping wild animals as pets is strongly discouraged. Any abnormal animal behavior or the presence of dead animals on residential property should be promptly reported to the local public health authority or animal control agency (Bonacho *et al*., 2020).

Control in animals: Post-exposure treatment (PET) of bite-contact unvaccinated carnivores, including dogs and cats is not recommended. Preliminary reports indicate that antibodies in the form of anti-rabies immunoglobulin (RIG) in combination with vaccine yielded poor results. The use of PET in animals is not without risk and is not recommended for use in animals (Franka *et al*., 2017).

Large-scale vaccination: This strategy represents the primary response to rabies outbreaks in endemic, high-risk areas. The objective should be to vaccinate at least 70% of the at-risk animal population through a single, intensive campaign conducted over the shortest possible time frame. In settings where this coverage cannot be achieved in a single effort, multiple vaccination campaigns-ideally two or more-should be implemented within the same year to ensure effective control (Rosenqvist *et al*., 2014).Together with One Health partners, the Ministry of Agriculture of Ethiopia has vaccinated more than 350,000 household pets in 2022 and 2023 as part of its efforts to eliminate rabies with a One Health approach andStepwise Approach towards Rabies Elimination(SARE) tools (Erkyihun *et al*., 2024).

Cordon vaccination: Cordon vaccination aims to create a barrier of animal immunity. Particularly in the vicinity of international and national borders, the cordon vaccination has become evidently important during the second phase of canine rabies elimination. A 20 to 30 km cordon area is usually preferred for this purpose (Knobel *et al*., 2014).

Ring vaccination: The long-distance transport of animals, particularly dogs that may be incubating the disease, is of increasing concern to veterinary authorities attempting to curtail the spread of rabies. This factor may result in outbreaks of canine rabies anywhere in the country at any time. It is therefore essential that immediate vaccination of the susceptible dog and cat populations be performed during the primary outbreak to prevent further exponential spread of the disease. Ring vaccination with a radius of 20 to 30 km, where at least 70 % of dogs are vaccinated, in areas where an isolated case has been diagnosed, has proven successful in controlling or eliminating rabies (Shi *et al*., 2020).

Door-to-door vaccination: Community-based strategies have proven highly effective in improving rabies control efforts. Home-to-home vaccination campaigns have been shown to significantly increase coverage. These approaches benefit from strong community engagement and are particularly suited to resource-limited, high-risk settings. To support monitoring and follow-up, the use of visible identifiers such as collars or neckbands on vaccinated dogs is recommended. Collectively, these practices contribute to more efficient and sustainable rabies vaccination programs (Mtshali, 2013).

Central-point vaccination: In rabies-endemic regions where outbreaks occur frequently, mass vaccination campaigns are typically conducted at least once annually. These programs often rely on pet owners bringing their animals to designated vaccination points. Achieving high coverage requires accurate epidemiological data, effective public outreach, and thorough logistical planning. Reported outcomes vary

widely, with vaccination coverage ranging from 20% to 80%, largely depending on the quality of implementation. Notably, higher participation rates are often observed when campaigns are initiated shortly after a widely publicized rabies outbreak (Balcha and Abdela, 2017).

Prevention in animals

Pre-exposure vaccination: Several recently developed thermo stable inactivated rabies vaccines are highly effective and offer immunity for one to three years. Most veterinary vaccines are species-specific, with no known safety concerns for use in other species (e.g., mongooses), but efficacy outside approved species is not guaranteed. All rabies vaccines must meet potency standards, with a minimum of 2.5 IU per dose. Puppies can start vaccination early, with boosters at three months and annually thereafter. Livestock vaccination schedules range from annual to triennial, depending on manufacturer guidelines. In rabies-endemic areas, some farmers vaccinate herds annually, especially when jackals and dogs are prevalent. After a rabies outbreak in livestock, animals without visible bite wounds should still be vaccinated. In contrast, those with bite injuries or confirmed exposure should be isolated and culled to prevent transmission (Balcha and Abdela, 2017).

Vaccination in wildlife: Mass oral vaccination of terrestrial wild animals is a widely accepted, feasible, and effective method for rabies prevention. This strategy is based on the principle of applied herd immunity and involves distributing vaccine-laden baits, which are effective when consumed by target wildlife species (Freuling *et al*., 2022).

Quarantine: The most effective method of preventing the entry of rabies into a country free of the disease is the imposition of a quarantine period of 4-6 months on all imported dogs. This system has successfully prevented the entry of the disease into island countries, but has obvious limitations in countries that have land borders (Garg, 2014).

Interprovincial movement restrictions: In rabies-endemic regions, the movement of domestic dogs and cats between provinces requires a valid rabies vaccination certificate. Puppies and kittens under three months can receive their first rabies vaccination at weaning and be transported immediately, provided they are revaccinated at three months. Before translocating carnivorous wild animals (e.g., jackals, mongooses, wild dogs, lions, leopards, cheetahs, hyenas), they must be vaccinated with an inactivated rabies vaccine. A valid rabies vaccination certificate must accompany any such movements (Anderson *et al*., 2016).

Avoidance of stray animals: Stray dogs, cats, and ferrets should ideally be removed from communities to help reduce the risk of disease transmission, including rabies. This effort can be more effectively enforced by local health departments and animal control authorities when owned pets are easily identifiable-through tags or microchips and are properly confined or kept on a leash. Clear differentiation between owned and stray animals not only simplifies enforcement but also helps protect both animal and public health (Goldberg, 2013).

Economic importance and zoonoses

Economic importance: The economic burden of rabies in a nation encompasses a wide range of components, including the costs associated with pet animal vaccinations, investigations of animal bite incidents, and the confinement or quarantine of domestic animals that have bitten individuals or are suspected of exposure to rabid animals. Additional expenditures arise from the salaries of animal control personnel, laboratory diagnostics, and the provision of both pre-exposure and post-exposure prophylaxis, along with associated medical treatment and expert consultation. Furthermore, costs related to public education initiatives, staff training programs, and administrative or clerical support also contribute significantly to the overall economic impact of rabies control and prevention efforts (Sofeu *et al*., 2018).

Zoonoses: Rabies is of prime concern due to its transmissibility to humans, with veterinarians at heightened risk. In regions with controlled canine rabies, human cases are rare, but over 30,000 people die from rabies annually, and more than 10 million receive post-exposure treatment after bites from rabid animals. In 2023, the WHO reported that dogs cause 99% of human rabies cases worldwide, with smaller contributions from cats, other domestic animals, bats, foxes, and other wild animals. Veterinarians, exposed to the virus through animal interactions, are particularly at risk and should receive pre-exposure prophylaxis. Rabid, aggressive horses also pose significant threats to humans. Public knowledge of rabies remains limited, and human rabies is still considered fatal once symptoms appear (Kabeta and

Fufa, 2018). In 2023, the tripartite collaboration between the World Health Organisation (WHO), the World Organisation for Animal Health (WOAH), and the Food and Agriculture Organisation (FAO), in conjunction with the Global Alliance for Rabies Control (GARC), revised the "Zero by 30: Global Strategic Plan". The revised strategy prioritises a One Health framework, incorporating mass dog vaccination (e"70% coverage), enhanced surveillance, intersectoral cooperation, and equitable access to post-exposure prophylaxis (PEP) to eradicate dog-mediated human rabies by 2030 (WHO *et al*., 2023).

Conclusion and recommendations: Rabies is a highly fatal disease of all mammals, and after the appearance of clinical signs, death is inevitable. When appropriate measures are taken, it is a preventable disease, and eradication is possible. The disease, in developing countries like Ethiopia, is perceived as an insignificant disease of humans and animals, and this factor has been a major reason hampering the development of disease control initiatives. From several studies, it can be concluded that many dogs are owned but not restricted by much of households, so that dogs can be infected by rabies and bite mammals, causing disease. There is a risk of rabies transmission through dog' bites and a rabies prevention measure upon exposure is not yet well practiced. Rabies is prevalent in several countries and the source of infection to humans and animals is dogs. Most post-exposure treatments given to them are primarily to dog's bites, but also the numbers of stray dogs in several countries are very large and those owned are not tied for the whole day.

Therefore, based on the above conclusion, it is recommended to effectively control rabies and manage the dog population, it is essential to implement a comprehensive strategy. Regular mass vaccination campaigns should be conducted and combined with continuing vaccination scheme for young dogs. It is necessary to have a regulation that enforces dog owners to vaccinate their dogs regularly and imposes a responsibility for all damages that they might cause to another person. Suspected animal should be quarantined for 10 days. Dogs that show clinical signs or have been in close contact with or bitten by a rabid animal should be destroyed. Additionally, wild fauna should be confined to designated protected areas to minimize interaction with domestic dogs. To further support this strategy, the capture and impounding of stray dogs must be reinforced, reducing the risk posed by unvaccinated and free-roaming animals in the community.

Conflict of interest: Authors declare that there was no conflict of interest.

Data availability statement: The data that support this study are available from the corresponding author upon reasonable request.

Author's Contribution: MP: conceptualized the topic and contributed to the final editing of the draft; RZ: conducted a detailed review of literature and drafted the initial manuscript draft; AB: contributed to the manuscript writing; TR: ensured comprehensive coverage of the topic; NP: contributed to the edition of the language, and clarity of the manuscript. All the authors contributed during the preparation of the manuscript.

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