



# Bio Vet Innovator Magazine

(Fueling The Future of Science...)

Volume 3 (Issue 9) SEPTEMBER 2026



World Rabies Day – 28<sup>th</sup> September 2026

Review Article

## Rabies in Livestock and Other Domestic Animals: An Updated Review

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DOI: <https://doi.org/10.5281/zenodo.23122801>

Received: September 29, 2026

Published: October 03, 2026

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### Abstract:

Rabies is a fatal, progressive viral encephalitis caused by Rabies lyssavirus (family Rhabdoviridae, genus Lyssavirus) that affects all warm-blooded animals, including livestock, companion animals and wildlife, and remains one of the oldest recognised zoonoses of veterinary and public health importance. Although dogs remain the principal reservoir and source of over 99% of human exposures worldwide, livestock species-particularly cattle, buffalo, goats, sheep, horses and pigs-are frequently infected through bites from rabid dogs, wildlife (foxes, jackals, mongoose, skunks and raccoons) and, in Latin America, the common vampire bat (*Desmodus rotundus*), resulting in substantial production and trade losses. This review synthesises current knowledge on the aetiology, global and Indian epidemiology, transmission dynamics and pathogenesis of rabies in livestock and other animals, with emphasis on species-wise clinical presentation across the furious, dumb (paralytic) and, less commonly recognised, atypical/abortive forms. Recent field reports (2024-2025), including a point-source rabies cluster in dairy steers in Minnesota, the first isolation of rabies virus from a Eurasian badger in Inner Mongolia with implications for wildlife-livestock spillover, and genetic characterisation of bovine rabies viruses in South Africa, illustrate the continuing ecological plasticity of the virus and the risk it poses to production animals even in regions with organised control programmes. Advances in laboratory diagnosis, notably the pan-lyssavirus LN34 real-time RT-PCR assay, are discussed alongside the classical direct fluorescent antibody test. The review presents a species-wise classification of clinical signs, differentiates the clinical forms, and consolidates current World Health Organization- and World Organisation for Animal Health-aligned recommendations on pre- and post-exposure prophylaxis in animals and in humans exposed to rabid or suspect livestock, including updated intradermal vaccination regimens. Gaps in surveillance, under-reporting in livestock, and the continuing need for mass dog vaccination and One Health coordination to achieve the global 'Zero by 30' target are highlighted, along with future research directions including oral wildlife vaccination, monoclonal antibody-based biologicals and improved point-of-care diagnostics.

**Key words:** Rabies; Lyssavirus; Livestock; Zoonosis; Furious form; Paralytic form; post-exposure prophylaxis; One Health

### 1. Introduction:

Rabies is an acute, invariably fatal viral encephalomyelitis of humans and all mammals, caused by neurotropic viruses of the genus Lyssavirus (family Rhabdoviridae), of which Rabies lyssavirus (RABV) is responsible for the overwhelming majority of animal and human cases worldwide (World Health

Organization [WHO], 2025). The disease has been recognised since antiquity and continues to cause an estimated 59,000 human deaths annually, more than 95% of them in Asia and Africa, with dog bites accounting for up to 99% of human exposures (Singh et al., 2017). Beyond its acute public-health burden, rabies is of substantial veterinary and economic importance: livestock-cattle, buffalo, goats, sheep, horses, camels and, occasionally, pigs-are 'dead-end' hosts that become infected chiefly through the bite of rabid dogs or wildlife, and outbreaks in herds and flocks cause direct mortality, loss of milk yield, trade restrictions, culling costs and, importantly, occupational exposure of farmers, para-veterinary staff and veterinarians who handle sick animals without adequate precaution (Escobar & Soler-Tovar, 2025).

In India and much of the developing world, rabies remains endemic and dog-mediated transmission continues to drive the disease in livestock populations that live in close proximity to free-roaming dog populations (National Action Plan for Dog-Mediated Rabies Elimination [NAPRE], 2024). India alone is estimated to carry close to one-third of the global human rabies burden, and outbreaks of rabies among cattle, buffalo and goats are regularly reported from field veterinary practice, although systematic livestock surveillance data remain sparse compared with human case reporting. This review brings together classical veterinary knowledge with recent (2023-2025) peer-reviewed findings to provide a comprehensive, field-usable reference on rabies in livestock and other animals for practising veterinarians, livestock development officers and students.

## 2. Aetiology and Taxonomy:

Rabies virus is a single-stranded, negative-sense RNA virus with a characteristic bullet-shaped virion (180 x 75 nm), belonging to genus *Lyssavirus*, family *Rhabdoviridae*, order *Mononegavirales*. The genome (~11.9 kb) encodes five structural proteins: nucleoprotein (N), phosphoprotein (P), matrix protein (M), glycoprotein (G) and RNA-dependent RNA polymerase (L). The glycoprotein is the principal determinant of pathogenicity, neurotropism and the target of virus-neutralising antibodies induced by vaccination. Phylogenetic analysis classifies RABV into major lineages-Africa, Asian, Cosmopolitan, Arctic-related and Indian subcontinent-with the Cosmopolitan lineage being globally dominant, including in most of India and China (Chen et al., 2025). At least 17 species are currently recognised within genus *Lyssavirus*; besides classical RABV, bat lyssaviruses (e.g., European bat lyssavirus, Australian bat lyssavirus) cause rabies-like disease but are of comparatively minor importance in livestock.

## 3. Epidemiology:

### 3.1 Global Situation:

Rabies is enzootic on all continents except Antarctica; only a small number of island nations (e.g., Australia for terrestrial rabies, Japan, and several Pacific and Caribbean islands) remain free of the disease. Reservoir hosts vary regionally: domestic dogs remain the principal reservoir across Asia, Africa and much of Latin America; foxes and raccoon dogs are important reservoirs in parts of Europe and East Asia; skunks,

raccoons and bats maintain distinct virus variants in North America; and the common vampire bat (*Desmodus rotundus*) is a major reservoir and source of livestock rabies across tropical Latin America (Soler-Tovar & Escobar, 2025). Historical WHO data record rabies prevalence of 61.4% in cattle and buffalo, 48.7% in goats, 45% in horses, 48% in dogs and 21.9% in cats among tested samples in endemic countries, underscoring that ruminants are disproportionately represented among confirmed rabid animals once exposed (Singh et al., 2017).

Recent surveillance continues to document spillover from wildlife reservoirs into livestock in areas previously considered low risk. In April 2024, an Eurasian badger (*Meles meles*) that attacked a shepherd's flock of sheep in Qingshuihe County, Inner Mongolia Autonomous Region, China, was confirmed rabid by whole-genome sequencing; the isolate (strain NMMeles-1) clustered with a bovine Cosmopolitan-lineage strain from the same region, representing the first documented rabies case in this species in China and suggesting badgers may act as an epidemiological bridge between fox reservoirs and domestic livestock (Chen et al., 2025). In the North West Province of South Africa, genetic and antigenic characterisation of rabies viruses recovered from cattle showed clustering with sequences from both domestic dogs and black-backed jackals, confirming bidirectional spillover between wildlife and cattle populations sharing communal grazing land (Khoane et al., 2025). In the United States, a point-source cluster of rabies was confirmed in five of thirty-five steers on a Minnesota dairy farm over a four-week period in May 2024, most likely originating from a single rabid skunk, although steer-to-steer transmission by direct contact could not be entirely excluded—an unusual finding, since cattle-to-cattle transmission is not considered a normal feature of the disease (Klumb et al., 2025).

### 3.2 Indian Scenario:

India launched the National Action Plan for Dog-Mediated Rabies Elimination by 2030 (NAPRE) in 2021, jointly by the Ministry of Health and Family Welfare and the Ministry of Fisheries, Animal Husbandry and Dairying, adopting a One Health framework that couples mass dog vaccination, animal birth control, improved dog-bite and PEP surveillance, and awareness generation (NAPRE, 2021; NAPRE, 2024). Rabies has been notified as a disease in several States, and government veterinary institutions are increasingly required to report suspect rabies cases in livestock, though under-reporting remains a recognised limitation because many field deaths are attributed clinically without laboratory confirmation. Livestock rabies in India is overwhelmingly dog-mediated, in contrast to the vampire-bat-driven epidemiology of Latin America, and outbreaks tend to be sporadic rather than clustered.

### 4. Transmission and Pathogenesis:

Transmission occurs principally through the bite of a rabid animal, when virus-laden saliva is introduced into a fresh wound; less commonly, infection follows contamination of mucous membranes or broken skin with infected saliva, or, in the case of vampire bats, through a shallow bite that may go

unnoticed by owners. Aerosol transmission is exceptionally rare but has been documented among people entering bat-infested caves. After inoculation, the virus replicates locally in myocytes near the bite site during a variable, clinically silent 'eclipse phase', then enters peripheral nerve endings and travels centripetally by fast retrograde axonal transport to the central nervous system, where it disseminates widely, producing non-suppurative polioencephalomyelitis. The virus subsequently spreads centrifugally along efferent nerves to highly innervated tissues, including the salivary glands, cornea, and skin of the muzzle, from where it is shed in saliva-explaining both the behavioural changes and the infectivity of the terminal patient.

Table 1. Comparative epidemiological features of rabies transmission in major world regions

| Region                      | Principal Reservoir/Source for Livestock       | Predominant Lineage               | Notable Recent Report                                                             |
|-----------------------------|------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------|
| South Asia (incl. India)    | Free-roaming dogs; occasional jackal/mongoose  | Indian subcontinent/ Cosmopolitan | NAPRE 2030 elimination programme; sporadic cattle/goat outbreaks                  |
| East Asia (China, Mongolia) | Dogs; foxes; emerging badger spillover         | Cosmopolitan; Arctic-like (AL2)   | First badger rabies isolate, Inner Mongolia, 2024 (Chen et al., 2025)             |
| Sub-Saharan Africa          | Dogs; jackals                                  | Africa lineage; Cosmopolitan      | Cattle-jackal-dog transmission network, South Africa (Khoane et al., 2025)        |
| Latin America (tropical)    | Vampire bat ( <i>Desmodus rotundus</i> ); dogs | Bat-associated variants           | Bat-transmitted cattle outbreaks, 1970-2023 review (Soler-Tovar & Escobar, 2025)  |
| North America               | Wildlife (skunk, raccoon, fox, bat)            | Terrestrial wildlife variants     | Point-source steer cluster from rabid skunk, Minnesota, 2024 (Klumb et al., 2025) |

The incubation period is highly variable, ranging typically from two weeks to three months, but documented from as little as nine days to several years, and is influenced by the site and severity of the bite (bites closer to the head and richly innervated areas shorten incubation), the viral dose inoculated, and the strain/lineage involved. In cattle, an average incubation period of about 15 days and a short morbidity period of approximately four days is commonly cited (NAPRE technical note, 2021), though incubation of several weeks to months also occurs.

5. Clinical Forms of Rabies:

Rabies classically progresses through three overlapping phases-prodromal, excitative (furious) and paralytic (dumb)-although the division has limited clinical value because signs vary greatly between individuals and species. In practice, the disease is conventionally described in three forms.

Table 2. Clinical forms of rabies and their principal features

| Form                             | Key features                                                                                                                                                    | Species in which most common                                                                                         | Duration/outcome                                                                      |
|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Prodromal (early) phase</b>   | Vague, non-specific signs: behavioural change, mild fever, apprehension, licking or biting at the wound site, appetite change                                   | All species                                                                                                          | Lasts 1-3 days before intensifying                                                    |
| <b>Furious (excitative) form</b> | Restlessness, hyperaesthesia, aggression, bellowing/vocalisation, biting at inanimate objects, photophobia, hypersalivation, seizures                           | Dogs, cats; occurs in ~25-45% of cattle and up to 43% of horses; goats often show aggression and continuous bleating | Rapidly progresses to paralysis and death within days                                 |
| <b>Dumb (paralytic) form</b>     | Progressive ataxia, depression, lower motor neuron paralysis of throat/masseter muscles, profuse salivation, dysphagia, dropped jaw, limb paralysis, recumbency | Most common overall presentation in cattle, horses and most livestock                                                | Progresses to coma, respiratory paralysis and death, usually within 2-6 days of onset |
| <b>Atypical/abortive form</b>    | Mild, self-limiting or intermittent neurological signs; occasionally survives past the usual course before deteriorating                                        | Reported occasionally in all species; rare and likely under-recognised                                               | Variable; ultimately fatal once true rabies is confirmed                              |

## 6. Species-Wise Clinical Signs:

Although the pathogenesis of rabies is common to all mammals, the behavioural expression differs considerably by species, which has important implications for on-farm recognition, occupational safety of handlers, and differential diagnosis. Table 3 summarises the principal species-wise clinical presentations reported in recent clinical and field literature.

Table 3. Species-wise classification of clinical signs of rabies

| Species                     | Predominant Form                                                 | Characteristic Clinical Signs                                                                                                                                                                                                                                                                                | Selected Reference                                |
|-----------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| <b>Cattle &amp; buffalo</b> | Dumb/paralytic (most common); furious form also occurs           | Sudden agalactia, altered (alert, wide-eyed) facies, characteristic intermittent abnormal bellowing, straining to urinate/defecate without result, hindlimb incoordination and weakness, drooling with inability to swallow, head-pressing, in furious form aggressive charging/attacking; death in 2-6 days | Merck Veterinary Manual, 2023; Klumb et al., 2025 |
| <b>Goats</b>                | Furious form most frequently reported; paralytic form documented | Aggression, continuous/abnormal bleating, restlessness, hyperaesthesia, profuse salivation; paralytic cases show apathy, herd isolation, sternal/lateral recumbency, ataxia, pedalling limb movements                                                                                                        | Moreira et al., 2018 (case report, Brazil)        |

|                                  |                                                  |                                                                                                                                                                                                                                    |                                                                |
|----------------------------------|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| <b>Sheep</b>                     | Signs resemble cattle                            | Restlessness, aggressive wool-pulling, hyperexcitability, drooling, incoordination; because sheep flock together, several animals may be exposed simultaneously by one rabid predator                                              | Ohioline Extension, 2022                                       |
| <b>Horses</b>                    | Dumb form in >50% of cases; furious form in ~43% | Muzzle tremors, pharyngeal paralysis, colic-like signs, anorexia, depression, ataxia, abnormal posture, frequent whinnying, unexplained aggression (kicking/biting/striking), head-tossing, transient lameness, apparent blindness | Rutgers NJAES FS1228; Ohioline Extension, 2022                 |
| <b>Pigs</b>                      | Furious form in majority of reported cases       | Anorexia, marked hyperexcitation, roaring/squealing, twitching of the head, constipation, foaming at the mouth, attacks on pen-mates                                                                                               | Pessoa et al., 2011; Jiang et al., cited in Vikas et al., 2021 |
| <b>Dogs (for context/vector)</b> | Both forms common; paralytic terminal in all     | Behavioural change, tenesmus, dropped jaw, change in bark, hypersalivation, progressing to ascending paralysis, coma                                                                                                               | Merck Veterinary Manual, 2023                                  |
| <b>Cats (for context/vector)</b> | Furious form most consistent                     | Abnormal vocalisation, photophobia, restless aggression, tremors, incoordination                                                                                                                                                   | Rutgers NJAES FS1228                                           |

## 7. Diagnosis:

Clinical diagnosis of rabies in livestock is presumptive; definitive confirmation is only achieved post-mortem by laboratory examination of brain tissue, since no reliable ante-mortem test exists for animals. Veterinarians are cautioned never to allow oral examination or bare-handed treatment of animals with unexplained dysphagia, excessive salivation or acute neurological signs, since owners and veterinary staff have been infected by handling the mouth of affected livestock while searching for a suspected foreign body.

### 7.1 Classical and Confirmatory Tests:

- **Direct Fluorescent Antibody Test (DFA/FAT):** the WHO/WOAH gold-standard test performed on brain impressions (hippocampus, brainstem, cerebellum); rapid (2-4 hours) and highly sensitive but requires a fluorescence microscope, high-quality conjugates and trained personnel.
- **Direct Rapid Immunohistochemical Test (DRIT):** a field-adapted alternative to DFA using light microscopy, useful where fluorescence facilities are unavailable.
- **Mouse Inoculation Test (MIT) / cell-culture isolation:** used historically and still applied for confirmation and strain isolation in reference laboratories.
- **RT-PCR and real-time RT-PCR:** increasingly used for confirmation, viral RNA detection in decomposed or fixed samples, and genotyping; the pan-lyssavirus LN34 real-time RT-PCR assay has recently been validated across multiple countries and laboratories with sensitivity of 99.7-100% and specificity of 99.99-100% compared with DFA, and is able to resolve indeterminate DFA results and

detect early infection in caudal brain structures before classical antigen distribution is complete (Gigante et al., 2025; Chierato et al., 2024).

- **Immunohistochemistry (IHC):** useful for formalin-fixed tissue when fresh/frozen brain is unavailable, though strain characterisation by IHC is limited.

## 7.2 Differential Diagnosis:

In livestock, rabies must be differentiated from other causes of acute neurological disease, including bovine spongiform encephalopathy, listeriosis, polioencephalomalacia, hypomagnesaemic tetany, lead and other toxic poisonings, botulism, tetanus, rabies-mimicking plant toxicities, and, where relevant, other viral encephalitides. A history of exposure to a known or suspected rabid animal, together with the rapidly progressive and invariably fatal course, strongly supports a clinical suspicion of rabies pending laboratory confirmation.

## 8. Prevention and Control:

### 8.1 Vaccination of Dogs (Source Reservoir Control):

Since dog-mediated transmission accounts for the overwhelming majority of livestock and human exposures in endemic countries, mass parenteral vaccination of owned and free-roaming dogs to reach and sustain at least 70% herd immunity coverage is recognised globally as the single most effective and cost-efficient intervention for interrupting the transmission cycle (NAPRE, 2024). India's NAPRE programme integrates dog vaccination with Animal Birth Control Rules, 2023, and improved bite/PEP surveillance under the Integrated Disease Surveillance Programme.

### 8.2 Vaccination of Livestock:

Killed (inactivated) rabies vaccines are licensed for cattle, horses and sheep in several countries, and off-label use of cattle/sheep vaccines in goats is commonly recommended by veterinarians in endemic areas, since no product is specifically labelled for goats. Annual pre-exposure vaccination of high-value livestock (dairy cattle, breeding stock, working equids) is recommended in areas where rabies is prevalent, both to prevent animal loss and to reduce occupational human exposure (Klumb et al., 2025). Where wildlife reservoirs (foxes, raccoon dogs, jackals) are important, oral rabies vaccination (ORV) of wildlife using vaccine-laden baits has successfully reduced wildlife rabies incidence in parts of Europe and North America and is being explored in other endemic settings.

### 8.3 General Biosecurity Measures:

- Secure housing and fencing of livestock to minimise contact with wild carnivores, bats and stray dogs, especially at night.
- Prompt isolation, and where warranted euthanasia under veterinary supervision, of any animal showing suggestive neurological signs, avoiding direct handling of the mouth and saliva.
- Use of personal protective equipment (gloves, face protection) by farm staff and veterinarians

examining or treating animals with unexplained dysphagia or behavioural change.

- Reporting of suspect cases to veterinary and public-health authorities in accordance with notifiable-disease requirements, and submission of brain tissue for laboratory confirmation whenever an animal dies of a suspect neurological illness.

## 9. Post-Exposure Management:

### 9.1 Management of The Exposed/Bitten Animal:

There is no approved treatment once clinical rabies develops in any species; the disease is essentially 100% fatal once signs appear, and affected animals should be humanely euthanised. For an unvaccinated domestic animal known to have been bitten by a confirmed or strongly suspected rabid animal, WOA-aligned guidance generally recommends either immediate euthanasia or, where the owner declines and the animal is of high value, strict quarantine and observation for a defined period (commonly four to six months) with immediate rabies vaccination at the time of exposure, since post-exposure vaccination of animals is not considered fully protective once exposure has occurred with a virulent strain. A previously vaccinated animal that is currently up to date should receive an immediate booster dose and a shorter observation period (typically 45 days), per national veterinary authority guidance.

### 9.2 Post-Exposure Prophylaxis (PEP) In Humans Exposed to A Rabid or Suspect Animal:

Any person bitten, scratched, or whose mucosa/broken skin is contaminated by the saliva of a rabid or suspect animal (dog, livestock or wildlife) requires immediate PEP, since rabies is virtually always fatal after onset of clinical signs but is essentially 100% preventable if PEP is correctly and promptly administered before symptom onset (Klumb et al., 2025; WHO, 2025). PEP has three components: thorough wound washing, rabies vaccination, and, for higher-risk (Category III) exposures, administration of rabies immunoglobulin (RIG) or, increasingly, monoclonal antibody products, in and around the wound.

- **Wound care:** immediate and thorough washing of all bite/scratch wounds and mucosal contamination sites with soap and running water for a minimum of 15 minutes, followed by application of an antiseptic (e.g., povidone-iodine); wound suturing should be delayed where possible.
- **Category I exposure** (touching/feeding animals, licks on intact skin): no PEP required if history is reliable.
- **Category II exposure** (minor scratches/abrasions without bleeding): wound care plus vaccination.
- **Category III exposure** (single or multiple transdermal bites/scratches, licks on broken skin/mucosa, contact with bat saliva): wound care, vaccination, and infiltration of RIG or rabies monoclonal antibody into and around all wounds.

The WHO now recommends intradermal (ID) administration of cell-culture rabies vaccine in preference to the traditional intramuscular (IM) route wherever feasible, since ID regimens use substantially less

vaccine (reducing costs by 60-80%) without compromising immunogenicity or safety. The commonly used 1-week, 2-site ID regimen (administered on Days 0, 3 and 7) has simplified PEP delivery considerably compared with older multi-visit IM schedules (WHO, 2025).

**Table 4. Representative WHO-aligned post-exposure prophylaxis (PEP) schedules for humans exposed to a rabid/suspect animal**

| Regimen                                                            | Route                                           | Schedule (Days)                                                | Typical Indication                                                                                   |
|--------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Essen<br>(5-dose IM)                                               | Intramuscular,<br>1 site/visit                  | 0, 3, 7, 14, (28 for<br>immunocompromised)                     | Where IM vaccine only<br>is available; category<br>II/III exposure                                   |
| Zagreb<br>(2-1-1, 4-dose IM)                                       | Intramuscular                                   | 0 (2 sites), 7 (1 site),<br>21 (1 site)                        | Alternative IM<br>schedule, fewer visits                                                             |
| WHO 1-week,<br>2-site ID (updated<br>TRC/IPC regimen)              | Intradermal,<br>2 sites/visit                   | 0, 3, 7                                                        | Preferred where ID<br>vaccination capacity<br>exists; dose- and cost-<br>sparing                     |
| 4-site ID,<br>2-visit regimen                                      | Intradermal,<br>4 sites Day 0;<br>2 sites Day 7 | 0, 7 ( $\pm$ Day 28)                                           | Economical option for<br>low-volume clinics;<br>recommended for<br>scale-up under Gavi<br>support    |
| Immunocompromised<br>regimen                                       | IM or ID per above,<br>plus extra dose          | Add dose on Day 28;<br>post-series antibody<br>testing advised | Immunosuppressed/i<br>mmunocompromised<br>patients                                                   |
| Rabies<br>immunoglobulin<br>(RIG) or monoclonal<br>antibody (RmAb) | Local infiltration in/<br>around all wounds     | Day 0 only, once                                               | All Category III<br>exposures; maximal<br>anatomically feasible<br>dose infiltrated at<br>wound site |

Persons occupationally exposed to livestock and wildlife-veterinarians, para-veterinary staff, livestock development officers, animal handlers and abattoir workers-are strongly advised to receive pre-exposure prophylaxis (PrEP), consisting of two vaccine doses (Days 0 and 7), which shortens and simplifies the PEP regimen required if a subsequent exposure occurs (WHO, 2025).

### 10. Recent Findings and New Observations (2023-2025):

- A rare point-source rabies outbreak among five dairy steers on a single Minnesota farm (May 2024) highlighted that clustering of rabies cases in cattle, though historically considered unusual, can occur from a single wildlife exposure event and that steer-to-steer transmission, while unproven, could not be excluded-reinforcing calls for pre-exposure vaccination of high-value cattle in enzootic areas (Klumb et al., 2025).
- The first confirmed isolation of rabies virus from a Eurasian badger in China (Inner Mongolia, 2024), with whole-genome sequencing showing 99.4% identity to a bovine cosmopolitan-lineage strain from the same region, demonstrates an expanding host range and possible new intermediate reservoirs bridging fox populations and domestic livestock (Chen et al., 2025).

- Genetic and antigenic characterisation of cattle-derived rabies viruses in South Africa's North West Province confirmed simultaneous circulation of dog- and jackal-associated lineages in cattle populations, underscoring that both domestic and wild carnivore reservoirs must be addressed together in livestock-dense, multi-host ecosystems (Khoane et al., 2025).
- A 1970-2023 continental review of vampire-bat-transmitted cattle rabies in Latin America found substantial and likely under-reported disease burden, attributable to limited field and laboratory surveillance capacity in remote pastoral regions, with outbreak sizes averaging about 14.6 cases and reaching over 1,300 cases in a single event (Soler-Tovar & Escobar, 2025).
- Validation studies of the pan-lyssavirus LN34 real-time RT-PCR assay across laboratories in the Americas, Africa, Asia and Europe, and specifically in Brazil, confirm that it can resolve indeterminate or false-negative results from the classical DFA test and detect early-stage infection, offering a practical path to strengthening rabies diagnostic capacity in resource-limited veterinary laboratories (Gigante et al., 2025; Chierato et al., 2024).
- WHO continues to promote transition from intramuscular to intradermal rabies vaccination for human PEP/PrEP and the use of monoclonal antibody products as an emerging, more sustainable alternative to polyclonal rabies immunoglobulin for wound infiltration (WHO, 2025).
- India's rabies elimination programme literature (2024-2025) emphasises 'catalytic response pathways' to accelerate dog vaccination coverage, surveillance, and PEP access, positioning India to work toward the global 2030 target despite its large stray dog population and persistent under-reporting of animal cases (NAPRE, 2024; Rabies elimination in India, 2025).

## 11. Research Gaps and Future Directions:

Despite decades of control effort, several gaps persist. First, livestock rabies surveillance remains largely passive and reactive in most endemic countries, leading to substantial under-reporting relative to the true disease burden, particularly in remote pastoral systems. Second, no rabies vaccine is specifically labelled for goats or camels in most jurisdictions, and off-label use, while pragmatic, complicates regulatory and efficacy assessment. Third, point-of-care, field-deployable ante-mortem diagnostic tools for livestock remain unavailable; expanding access to RT-PCR-based platforms such as LN34 in regional veterinary laboratories would substantially improve both individual case confirmation and outbreak characterisation. Fourth, the expanding recognition of atypical reservoirs (e.g., badgers) and unusual transmission patterns (e.g., possible direct animal-to-animal spread in confined cattle) calls for continued genomic surveillance and One Health data-sharing between animal and human health sectors. Finally, sustained investment in mass dog vaccination, oral wildlife vaccination pilots, and integration of livestock vaccination into national rabies elimination strategies will be essential if the global 'Zero human deaths from dog-mediated rabies by 2030' target set by WHO, WOA, FAO and GARC is to be met.

## 12. Conclusion:

Rabies remains a uniformly fatal but entirely preventable disease that continues to threaten livestock health, farmer livelihoods and public health across most of the world. Species-specific recognition of clinical signs-ranging from the classical furious and dumb forms to less common atypical presentations-remains central to timely suspicion, safe handling and laboratory confirmation. Recent field reports demonstrate that the ecology of rabies virus continues to evolve, with new reservoir hosts and unusual transmission clusters being documented even in well-resourced surveillance systems, while diagnostic science has advanced meaningfully through pan-lyssavirus molecular assays. Prevention rests on the interlinked pillars of mass dog vaccination, targeted livestock and occupational human vaccination, farm-level biosecurity, and prompt, correctly administered post-exposure prophylaxis using current WHO-recommended intradermal regimens. Achieving the global goal of zero human rabies deaths by 2030 will require sustained One Health collaboration between veterinary, medical and wildlife authorities, with livestock development officers and field veterinarians playing a frontline role in surveillance, farmer education and timely referral of suspect cases.

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### Author's Contribution and Disclosure:

Dr. Hrishikesh Jagtap and all others are responsible for the conception, literature review, drafting and final approval of this manuscript. The author declares no conflict of interest.