Estimates of the burden of human rabies deaths and animal bites in India, 2022–23: a community-based cross-sectional survey and probability decision-tree modelling study

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Summary

Background Reliable and recent data of human rabies deaths and animal bites are not available in India, where a third of global cases occur. Since there is a global target of eliminating dog-mediated human rabies by 2030, understanding whether the country is on track is essential. We aimed to estimate the animal-bite burden and the number of human rabies deaths in India.

Methods We conducted a community-based nationwide cross-sectional survey with a multistage cluster-sampling design from March 2, 2022 to Aug 26, 2023, covering 60 districts in 15 Indian states. The head of the household or an adult family member was interviewed to collect information about animal-bite history in family members, receipt of anti-rabies vaccination (ARV), and death following animal bite in the family. Annual animal-bite incidence along with 95% CIs were estimated after applying the sampling weights and adjusting for clustering. We estimated annual human rabies deaths using a decision-tree probability model with parameters from the community survey and laboratory data on rabies positivity among suspected rabid dogs.

Findings Of the 337 808 individuals residing in the 78 807 households surveyed, 2052 gave a history of animal bite, mostly (1576 [76·8%]) due to dogs in the past 1 year. The weighted and adjusted annual incidence of animal bite was 6·6 (95% CI 5·7–7·6) per 1000 population, translating into 9·1 million bites nationally. Annual dog-bite incidence was 5·6 (4·8–6·6) per 1000. Among people who had been bitten by a dog, 323 (20·5%) did not receive ARV, and 1043 (66·2%) received at least three doses. Nearly half (615 [49·1%]) of the 1253 individuals who received one dose did not complete their full course of vaccination. We estimated 5726 (95% uncertainty interval 3967–7350) human rabies deaths occurring annually in India.

Interpretation Although there was a substantial decline in human rabies deaths over the past two decades, to eliminate dog-mediated human rabies by 2030, India needs to fast-track its actions by adopting a focused one-health approach. Integrating human and animal surveillance, ensuring timely administration of full course of post-exposure prophylaxis, and accelerating dog vaccination across the country are crucial steps towards this goal.

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Introduction

Rabies, a fatal but vaccine-preventable viral zoonotic disease, causes approximately 59 000 human deaths globally each year, mostly because of dog bites.[1] United Against Rabies, an alliance of partners from international agencies, has made a global call to end human deaths from dog-mediated rabies by 2030 (Zero by 30).[2] To achieve this goal, India has laid a roadmap through its National Action Plan for Dog-Mediated Rabies Elimination from India by 2030 (NAPRE).[3] NAPRE envisages a one-health approach, involving human and veterinary health sectors, the Agriculture Ministry, municipal corporations, and Panchayati Raj Institutions to achieve 75% dog-vaccination coverage by 2025, and 75% reduction in human rabies deaths by 2030. The key component of the action plan includes mass dog vaccination, ensuring availability of rabies biologicals free of cost at all levels of the health system and strengthening linkages between rabies surveillance in humans and animals.

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See Online for appendix

Research in context

Evidence before this study

We searched PubMed and Embase on June 11, 2024, for articles reporting estimates on human rabies deaths and animal-bite incidence in India, using search terms such as "burden", "incidence", "mortality", and "death" in combination with "rabies", "animal bite", "dog bite", and "India", published in English since Jan 1, 2004. We identified four studies related to human rabies deaths estimation; two modelling studies done in 2005 and 2015, one verbal autopsy study for deaths that occurred in 2005, and a community-based survey done in 2003. All the studies estimated around 20 000 human rabies deaths per year except for the verbal autopsy study, which reported 12 700 deaths. Additionally, we identified 40 articles reporting animal or dog-bite incidence. Of these, 31 were hospital-based studies, and nine were community-based studies. A systematic review done in 2021 reported crude annual dog-bite incidence to be between 0·26% and 2·50%. However, all the studies were done in small geographical areas, using convenient sampling methods within the catchment area of tertiary-care hospitals and did not have generalisability. Human rabies surveillance data in India are unreliable. In this context, we did a nationwide community survey to estimate animal-bite burden, human rabies deaths, and post-exposure prophylaxis (PEP) coverage.

Added value of this study

Current estimates on human rabies death burden, animal-bite burden, and PEP coverage are crucial for India to prioritise strategies to achieve the global goal of eliminating dog-mediated human rabies by 2030 (the Zero by 30 goal). A population-based nationwide survey to obtain information on bite burden and human rabies deaths has not been done in the past two decades. Our survey spanned different regions of India, covering a wide geographical area to ensure representative estimates at national and regional levels. Our study findings indicated that around 9·1 million animal bites occur every year in India, with the majority caused by dogs. Although 80% of the dog-bite victims received one dose of anti-rabies vaccination, only two-thirds received three doses, and 40% completed the prescribed vaccination schedule. Only a tenth of the eligible bite victims received passive immunisation. Our survey also found that around half of the pet dogs in the households were not vaccinated against rabies. We used the information from the survey and animal laboratories and estimated 5726 human rabies deaths per year using the probability decision-tree model, showing nearly a 75% decrease in the number of deaths in the past 20 years.

Implications of all the available evidence

Newer estimates will have substantial implications on the global burden of rabies, given that India contributes around 35% of the global human rabies death burden. Findings from this study will provide clarity on the current status of this burden and enable the programme managers to prioritise their strategies and tailor their efforts to eliminate dog-mediated rabies by 2030. Specifically, India needs to adopt a one-health approach by integrating human and animal surveillance, ensuring timely administration of a full course of PEP for all bite victims, and prioritising scale-up of mass dog vaccination across the country.

In India, 17·4 million animal bites occur annually, resulting in 20 565 human rabies deaths.[4,5] A multicentric community survey on animal bites done in seven states in 2017 demonstrated an anti-rabies vaccination (ARV) coverage of 79·6%.[6] An evaluation of the human rabies surveillance system indicated a substantial under-reporting of the number of bites and human rabies death burden.[7] The last nationwide survey to estimate human rabies deaths and animal-bite burden was done in 2003, and this type of up-to-date country-specific data are necessary for reliable global estimates.[8] In this context, we did a community-based cross-sectional survey across India to estimate animal-bite incidence. Using relevant parameters from the survey, we estimated the number of human rabies deaths using a probability decision-tree model.

Methods

Study design and participants

India has 788 districts across 28 states and eight union territories. We did a community-based nationwide cross-sectional survey in 60 districts across 15 Indian states between March 2, 2022, and Aug 26, 2023 using a multistage cluster-sampling design. For sampling purposes, we divided India into five geographical regions (north, south, east, west, and northeast). We selected three states from each geographical region using simple random sampling. In each state, we selected four districts using the probability proportional-to-size (PPS) method. Within each district, we selected ten clusters (villages in rural areas and wards in urban areas) using the PPS method. From each cluster, we randomly selected one census enumeration block (geographical area within a village or ward delineated as part of decadal census with around 130–150 households; figure 1; appendix p 1).

Assuming an animal-bite incidence of 1·7%,[5] relative margin of error of 10%, design effect of 2%, confidence level of 95%, and non-response of 15%, we required a sample size of 52 267 people per geographical region. With a minimum household size of 3·5 (census 2011), we needed to cover approximately 15 000 households (around 5000 households per state) in each region. Therefore, a minimum of 140 households were to be visited in each cluster to reach the sample size.

In each selected cluster, the study team visited 140 households sequentially after randomly selecting the

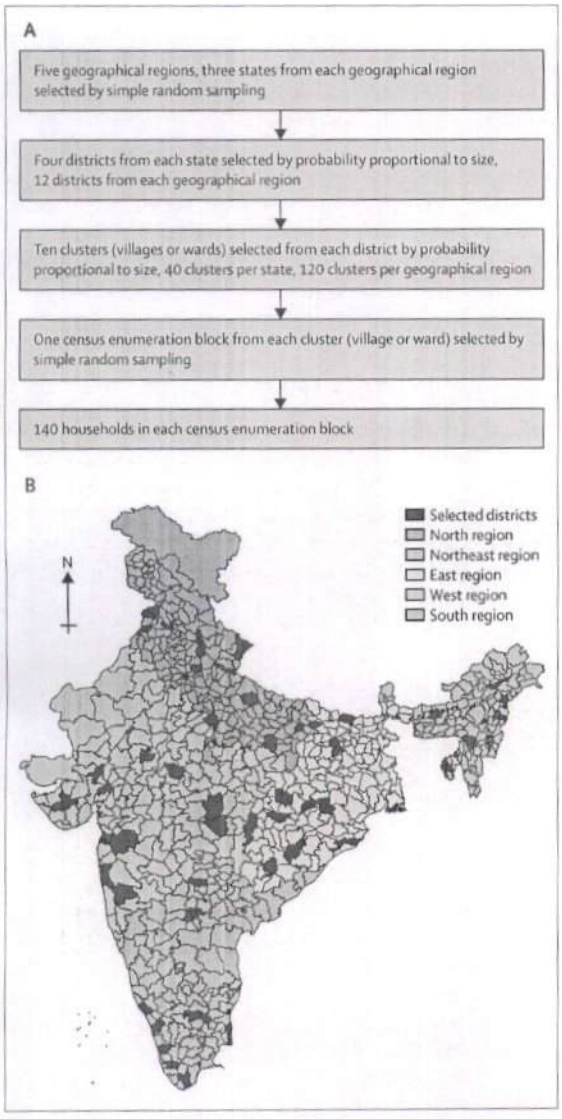

Figure 1: **Sampling strategy, study districts**
(A) Multistage cluster-sampling design employed for the survey. (B) Map of the 60 selected study districts from 15 states across five regions in India. The map was created in QGIS version 3.34. The shape file was adapted by permission of the Survey of India.

	Study participants
Age, in years (n=337 808)	
0–14	78 866 (23·4%)
15–60	230 743 (68·3%)
>60	28 199 (8·3%)
Median (IQR)	28 (15–45)
Gender (n=337 808)	
Male	171 344 (50·7%)
Female	166 299 (49·2%)
Other	165 (0·1%)
Education of the head of the household (n=78 807)	
Professional, or honours or graduate degree	9208 (11·7%)
Senior or higher secondary (grade 11 and 12)	10 063 (12·8%)
High-school certificate (grade 9 and 10)	18 241 (23·1%)
Middle-school certificate (grade 6–8)	14 228 (18·0%)
Primary-school certificate (grade 1–5)	13 370 (17·0%)
Illiterate, or can read and write with no formal education	13 697 (17·4%)
Occupation of the head of the household (n=78 807)	
Professional, managers, officials, and legislators	1747 (2·2%)
Technicians and associate professionals	2719 (3·4%)
Clerks or clerical support workers	3368 (4·3%)
Service and sales workers	18 133 (23·0%)
Agricultural and fishery workers	27 580 (35·0%)
Craft and related trade workers	16 069 (20·4%)
Homemaker	3354 (4·3%)
Unemployed	2591 (3·3%)
Retired	3246 (4·1%)
Type of house (n=78 807)	
Pucca	42 084 (53·4%)
Semi-pucca	20 695 (26·3%)
Kuccha	16 028 (20·3%)
Toilet facility (n=78 807)	
Own toilet (outside or inside the house)	61 288 (77·8%)
Shared common toilet	10 605 (13·5%)
Public toilet	1139 (1·4%)
Use open space	5775 (7·3%)

Table 1: **Sociodemographic characteristics of study participants**

first household. If the selected census enumeration block did not have 140 households, households in the adjacent census enumeration block were included. Trained investigators, using Open Data Kit software on a tablet, collected demographic details and histories of animal bites and deaths caused by animal bite over the past 5 years for all the usual family members residing in the household. Additional information including the type of biting animal, status of the animal after the bite, circumstances leading to the animal bite, and receipt of post-exposure prophylaxis (PEP) was collected for individuals reporting history of animal bites. Dog bites identified during the survey were classified as bite by a normal or suspected rabid dog using the criteria proposed by Tepsumethanon and colleagues.[9]

Institutional Human Ethics Committee of the Indian Council of Medical Research–National Institute of Epidemiology and participating institutions approved the study protocol. We obtained written informed consent from participants older than 18 years, parental consent from those younger than 17 years, and assent from participants aged 7–17 years.

Statistical analysis

We used proportions, mean (SD), and median (IQR) to describe household and participant characteristics. We computed overall weighted annual incidence of animal

	Animal
Animal bites reported in the past 1 year	2052
Dog bites reported in the past 1 year	1576
Biting animal (n=2052)*	
Dog	1576 (76·8%)
Cat	385 (18·8%)
Monkey	48 (2·3%)
Rat	25 (1·3%)
Other (donkey, cow, domestic pig, rabbit, jackal, or leopard)	18 (0·8%)
Category of dog (n=1576)	
Pet	614 (39·0%)
Stray	962 (61·0%)
Nature of attack (n=1576)	
Unprovoked attack	1281 (81·3%)
Provoked attack	295 (18·7%)
Availability of the dog for 10 days (n=1576)	
Available	1144 (72·6%)
Status of the dog after 10 days (n=1144)	
Alive	1066 (93·2%)
Died	31 (2·7%)
Killed within 10 days	22 (1·9%)
Not known	25 (2·2%)
Number of wounds (n=1576)	
One	1457 (92·4%)
Two	88 (5·6%)
More than two	31 (2·0%)
Site of bite (n=1734)	
Lower limbs (leg or feet)	1182 (68·2%)
Upper limbs (arm, forearm, or hands)	428 (24·7%)
Torso	75 (4·3%)
Head or face	49 (2·8%)
Type of wound (n=1734)	
Abrasion	1130 (65·2%)
Laceration	394 (22·7%)
Puncture wound	196 (11·3%)
Avulsion	14 (0·8%)

*Number (% of total).

Table 2: Characteristics of the biting animal and profile of the bites

and dog bites along with 95% CIs using design weights and adjusting for clustering. We calculated the product of probability of selection of sampling units at each stage and took its inverse to calculate the design weight. Design weight was adjusted for the non-response to calculate the final sampling weight (appendix p 2). We also calculated weighted-bite incidence by age groups, gender, and type of residence along with 95% CIs. In addition, we calculated the PEP coverage for ARV by doses, receipt of rabies immunoglobulin, and wound care. We did a cluster-adjusted univariable and multivariable logistic regression analysis to identify factors associated with non-receipt of ARV. Variables with $p<0·20$ in the univariable analysis were included in the final model.

We used the WHO recommended decision-tree dog-bite probability model to estimate human rabies deaths by using a series of probability steps developed by Cleaveland and colleagues[10] and used for estimation of national and global burden.[1,10,11] The input parameters from the community survey included annual incidence of suspected rabid dog bites, ARV coverage, and distribution of dog-bite wounds on the body. The data on rabies positivity among suspected rabid dogs was obtained from six veterinary laboratories catering to 12 Indian states. Estimated human rabies deaths were obtained by multiplying the incidence of suspected rabid dog bites from community survey by the probability of death after being bitten by a suspected rabid dog (appendix pp 3–4). We estimated 95% uncertainty interval (UIs) for the estimated human rabies deaths by using a Monte Carlo simulation for 10000 iterations. Furthermore, we did a sensitivity analysis using the lower and upper CIs of animal rabies positivity data and average incidence of suspected rabies dog bite over a 3-year period. The data were analysed using the survey data analysis module in STATA SE version 17.0, and R version 4.2.2.

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We surveyed 78807 (91·2%) of the 86444 households (the reasons certain households were not included in the survey are presented in the appendix p 5). History of dog bite was collected for 337808 individuals from these households (appendix p 5). The median age of the survey participants was 28 years (IQR 15–45) years, and 171344 (50·7%) were men and 166299 (49·2%) were women. 13697 (17·4%) heads of household (ie, the person who was usually responsible for the upkeep, maintenance, and made the financial decisions of the household) were illiterate, 42084 (53·4%) resided in pucca houses, and 73032 (92·7%) reported that they used either their own, shared, or a public toilet facility (table 1).

2052 individuals reported a history of animal bites in the past year, with 1576 (76·8%) attributed to dogs (table 2). The annual unweighted animal-bite incidence was 6·1 (95% CI 5·8–6·3) per 1000 population and the annual incidence of dog bite was 4·7 (4·4–4·9) per 1000 population. The weighted incidence after adjusting for clustering was 6·6 (5·7–7·6) for animal bite and 5·6 (4·8–6·6) for dog bite per 1000 per year. Annual dog-bite incidence was 7·5 per 1000 among children aged 0–14 years, 7·8 per 1000 among people older than 60 years, and 7·6 per 1000 among male individuals and 3·5 per 1000 among females. The dog-bite incidence was 5·8 per 1000 in rural areas and 5·0 per 1000 in urban areas (figure 2; appendix p 6). The annual dog-bite

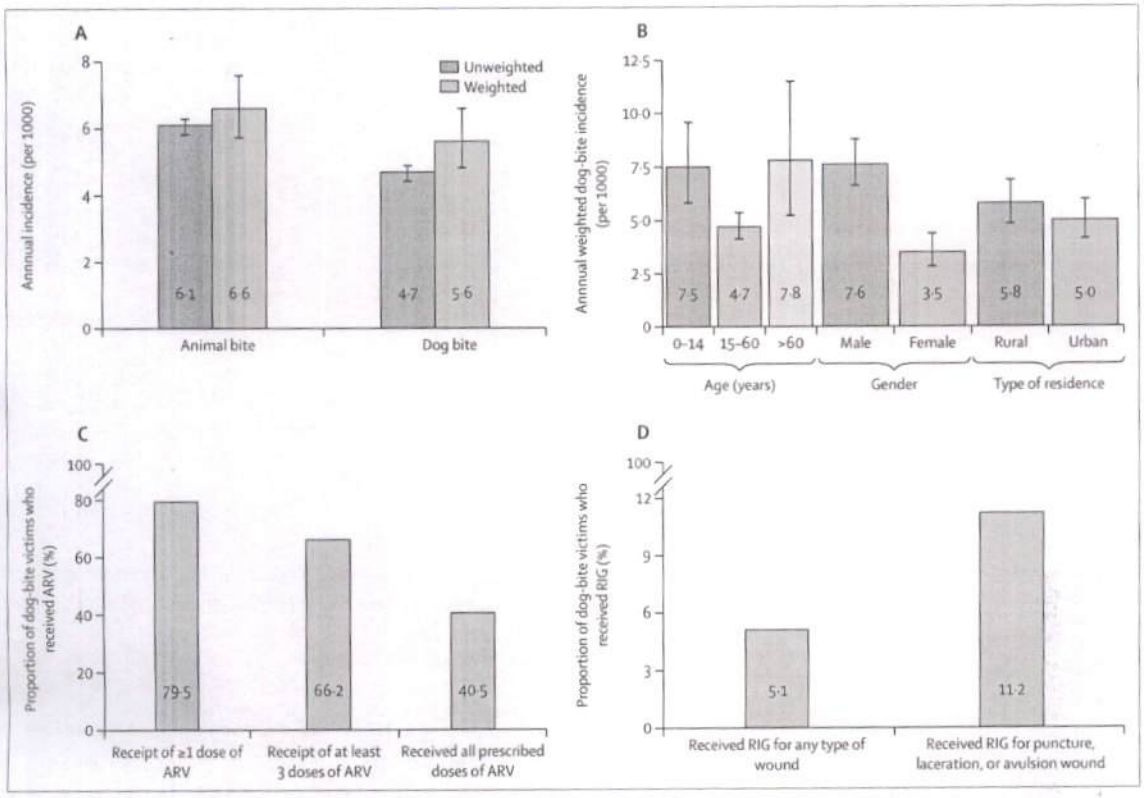

Figure 2: **Annual incidence of animal and dog bites overall and by demographic characteristics and post-exposure prophylaxis coverage among bite victims**
(A) Comparison of unweighted and weighted annual incidence of animal bite and dog bite per 1000 population. Lines at the top of each bar represent 95% CIs. (B) Annual weighted dog-bite incidence by age, gender, and type of residence per 1000 population. Lines at the top of each bar represent 95% CIs. (C) Proportion of people bitten by dogs receiving ARV for at least one dose, three doses, and after completion of the prescribed schedule. (D) Proportion of people bitten by dogs who received RIG for various types of wounds. ARV=anti-rabies vaccine. RIG=rabies immunoglobulin.

incidence ranged between 3·8 to 7·6 per 1000 in different regions (appendix pp 8, 21).

Of the 1576 dog bites reported, 614 (39·0%) were by pet dogs and 1281 (81·3%) were unprovoked attacks. 1144 (72·6%) dogs were available for monitoring of their health status for 10 days, of which 1066 (93·2%) were alive after 10 days, 31 (2·7%) died, and 22 (1·9%) were killed. Most bites resulted in a single bite wound, predominantly on the lower limbs, upper limbs, torso, and the head or face. The most common type of wound was abrasion, followed by laceration, puncture wound, and avulsion (table 2).

Of the 1576 bite victims, 849 (53·9%) reported washing their wounds with soap and water and 276 (17·5%) applying some locally available remedies, such as chilli and turmeric powder (table 3). 1317 (83·6%) sought medical care at health facilities, with most seeking care within 24 h (appendix p 6).

Among people who had been bitten by dogs, 1253 (79·5%) received at least one dose of ARV, 1043 (66·2%) received three doses, and 638 (40·5%) received all the prescribed doses (figure 2; table 3; appendix p 7). Of the 1253 individuals who received at least one dose of ARV, 615 (49·1%) did not complete their full course of vaccines (appendix p 7). Of those who took vaccination, 1121 (89·5%) obtained it from public health facilities and 836 (66·7%) were administered intradermally (table 3). The most common reasons for not taking the vaccine among unvaccinated individuals were lack of awareness, no belief in vaccination, and a minority took treatment from a traditional healer (appendix p 7). On multivariable analysis, odds of non-receipt of ARV were higher among dog-bite victims residing in north, northeast, east, and west regions. Other factors associated with non-receipt of ARV were bite victims with abrasion, being bitten by pet dogs, and residence in kuccha houses (appendix pp 9–11).

Only 81 (5·1%) bite victims reported taking rabies immunoglobulin. Among the 546 individuals with laceration, puncture, or avulsion wounds, only 61 (11·2%) had received rabies immunoglobulin (figure 2; table 3), mostly from public health facilities at the district and subdistrict levels (table 3).

Nearly a fourth of households interviewed reported having a pet or domestic animal. Of these, 3714 (18·6%) households reported that they had a pet dog and around half of the pet dogs were vaccinated (appendix p 12).

	People bitten by dogs
Wound management (n=1576)	
Wash with water and soap	849 (53·9%)
Locally available application	276 (17·5%)
Applied antiseptic	284 (18·0%)
Locally available application (n=276)	
Chilli powder	109 (39·5%)
Turmeric powder	107 (38·8%)
Plant sap or coconut water	10 (3·6%)
Other (mud, coffee powder, cow dung, coin snuff, powdered tablet, oil, or salt)	50 (18·1%)
ARV coverage by doses (either intradermal or intramuscular)	
Zero doses	323 (20·5%)
One dose	84 (5·3%)
Two doses	126 (8·0%)
Three doses	318 (20·2%)
Four doses	591 (37·5%)
Five doses	134 (8·5%)
Type of health facility ARV was received (n=1253)	
Public health facility (primary health centre or community health centre district hospital or subdistrict hospital or Taluk hospital medical college hospital)	1121 (89·5%)
Private health facility	132 (10·5%)
Route of administration (n=1253)	
Intradermal	836 (66·7%)
Intramuscular	417 (33·3%)
Site of ARV vaccination (n=1253)	
Deltoid	1217 (97·1%)
Anterolateral thigh	11 (0·9%)
Gluteal	25 (2·0%)
Received rabies immunoglobulin (n=1576)	81 (5·1%)
Type of health facility rabies immunoglobulin was received (n=81)	
Public health facility (primary health centre or community health centre district hospital subdistrict hospital or Taluk hospital or medical college hospital)	73 (90·1%)
Private health facility	8 (9·9%)
Type of bite wound and rabies immunoglobulin receipt	
Avulsion (n=11)	3 (27·3%)
Puncture (n=179)	30 (16·8%)
Laceration (n=356)	28 (7·9%)
Abrasion (n=1030)	20 (1·9%)

ARV=anti-rabies vaccination.

Table 3: Post-exposure prophylaxis coverage among dog-bite victims

69 (4·4%) of the 1576 dog bites were classified as bites by suspected rabid dogs (appendix p 13), with the annual incidence of around 2·0 per 10 000 population.

Between 2017 and 2022, 1880 suspected rabid dogs were tested by six rabies laboratories, with 1407 (74·8%) testing positive for rabies on direct fluorescent antibody testing (appendix p 14).

Of the 69 bites by suspected rabid dogs, 42 (60·9%) were on legs, 19 (27·5%) were on arms, six (8·7%) were on torsos, and two (2·9%) were on the head or face. 54 (78·3%) bite victims received at least three doses of ARV.

On the basis of the aforementioned data, the probability of death when bitten by a suspected rabid dog estimated using the decision-tree model was around 2% (table 4).

Using the annual incidence of suspected rabid-dog bites and the probability of death when bitten by a suspected rabid dog, we estimated 5726 (95% UI 3967–7350) human rabies deaths occur in India annually (table 4). The sensitivity analysis estimated 3908 (2741–5016) annual deaths based on the average bite incidence over the past 3 years. Considering the upper and lower 95% CIs of the data on rabies positivity among suspected rabid dogs, the estimated deaths were 5879 (95% UI 4078–7560) for the upper limit and 5573 (3897–7165) for the lower limit of rabies positivity among suspected rabid dogs (appendix p 15).

Discussion

Our survey estimated the annual incidence of animal bites in India to be 6·6 per 1000 persons, translating to 9·1 million bites annually, mostly caused by dogs. Nearly, two-thirds of the dog-bite victims had taken at least three doses of ARV. We estimated around 5700 human rabies deaths occur annually in India.

A systematic review in 2021 reported crude annual dog-bite incidence to be between 0·26% and 2·5%, with most studies reporting an incidence higher than 2%.[12] The dog-bite incidence observed in our study was lower than earlier studies. Higher incidences in earlier studies could be due to their smaller geographical scope and absence of probability sampling design. Our survey was nationally representative, using probability sampling at all levels of selection, with adequate sample size from each region of India. Another possible reason for lower incidence could be due to COVID-19 movement restrictions. However, the 1-year recall period of animal-bite history in 14 of the 15 states was after COVID-19 movement restrictions were lifted (appendix p 16), suggesting that our estimates might not have been greatly influenced by the pandemic. In 2019, the National Rabies Control Programme (NRCP) reported 7·2 million animal bites based on facility reporting.[3,13] Our estimates of 9 million bites is close to the NRCP data before COVID-19, considering 20% of bite victims do not attend health facilities and 10% seek care from private health facilities.

Earlier studies in India estimated around 20 000 human rabies deaths annually.[1,4,11] Compared to these estimates, there has been a substantial decline, nearly 75%, in deaths over the past two decades. Analysis of data from the National Health Profile also showed a significant decline in incidence of human rabies death from 2·36 to 0·41 per 10 million population between 2005 and 2020.[14] The decrease in deaths could be due to increased coverage of PEP among dog-bite victims. A

nationwide study conducted in 2003 indicated 30·5% coverage of ARV and 2% coverage of rabies immunoglobulin in dog-bite victims.[5] In our study, ARV coverage was 66·2% and rabies immunoglobulin coverage was 11·2%. Availability of ARV free of charge at public health facilities and greater awareness regarding ARV could have contributed to the increased ARV coverage.[7,15]

Given that rabies is a fatal disease, timely, complete, and appropriate PEP is crucial. 20·5% of bite victims did not receive any ARV, with absence of awareness being the most common reason for non-vaccination. Dog-bite victims with abrasion were more likely not to take ARV, possibly underestimating the severity of small wounds. Focused IEC messaging is needed to stress the importance of seeking medical care even for minor abrasion.

Two-thirds of the bite victims in our survey received at least three doses and only 40·5% completed their scheduled course of vaccination. Additionally, about half of the bite victims who received one dose did not complete their full course of vaccination. Currently, in India, the scheduled dates of vaccination are written on outpatient sheets and bite victims are advised to come on scheduled vaccination dates. However, there is no system to remind the bite victims about their due dates of vaccination. Implementing reminder mechanisms such as SMS or automatic voice calls, and in-person visits or telephonic calls from health workers can reduce dropouts. NRCP could also consider adopting the WHO-recommended shortened 1-week abridged Cambodia regimen[16] for better compliance. Our study indicated that 50–67% of bite-victims from northeastern and eastern states received ARV intramuscularly. NRCP should advocate intradermal administration of ARVs in the deltoid region.

Only 11·2% of eligible bite victims in our survey reported receipt of rabies immunoglobulin, mostly from tertiary-care facilities. Making rabies immunoglobulin widely available in public health facilities is challenging because of limited production and high cost.[17] Alternatively, use of rabies monoclonal antibodies could be considered with adequate training of health staff for correct use. Around half of the bite victims washed their wounds with soap and water and 17·5% used irritants such as turmeric and chilli powder. Such practices might delay care seeking and must be discouraged through continuous awareness by IEC messaging to the community.

In India, data on suspected human rabies deaths and animal bites are collected through the Integrated Health Information Portal of Integrated Disease Surveillance Programme.[18] Additionally, NRCP collects this information from public health facilities once per month.[19] During 2012–22, NRCP reported 6644 suspected human rabies cases and deaths, whereas the National Health Profile reported 2863 cases between 2005 and 2020 on the basis of health management information system data.[3,14] However, our study estimated around 5700 human rabies deaths every year. The under-reporting of rabies deaths could be caused by incomplete reporting from health institutions, deaths occurring outside hospital settings, patients not getting admitted to hospital, and misdiagnosis. One major barrier to reporting human rabies cases is that victims either rarely get or do not get admitted to hospital. Additionally, the majority of human rabies cases are suspected based on clinical symptoms and laboratory confirmation is not routinely feasible in all suspected cases. Human rabies is a notifiable disease in India,[20] and states need to leverage such legal framework to improve accurate and timely reporting of all suspected human rabies cases occurring within and outside health facilities.

Rabies surveillance in animals in India is limited to ad-hoc reporting of suspected rabid animals to selected veterinary laboratories,[21] with no integration between human and animal surveillance systems. Integrated

	1-year survey data	Data source
Number of suspected rabid dog bites	69	Dog bites identified in the community survey were classified using Tepsumethanon's six criteria
Probability of a suspected rabid dog being confirmed rabid on laboratory diagnosis (1407 of 1880)	Binomial distribution: p=0·748	Using data from six laboratories in 12 Indian states
Bite injury to the head or neck (point estimate)	0·0290	Community survey data
Bite injury to the hand or arm (point estimate)	0·2754	Community survey data
Bite injury to the torso (point estimate)	0·087	Community survey data
Bite injury to the leg or foot (point estimate)	0·6087	Community survey data
Probability of developing rabies following a bite injury to the head by a rabid dog	Triangular distribution: minimum 0·30, mode 0·45, and maximum 0·60	Cleaveland et al[10]
Probability of developing rabies following a bite injury to the hand or arm by a rabid dog	Triangular distribution: minimum 0·15, mode 0·28, and maximum 0·40	Cleaveland et al,[10] Knobel et al,[11] and Fèvre et al[23]
Probability of developing rabies following a bite injury to the torso by a rabid dog	Triangular distribution: minimum 0·00, mode 0·05, and maximum 0·10	Cleaveland et al,[10] Knobel et al,[11] and Fèvre et al[23]
Probability of developing rabies following a bite injury to the leg or foot by a rabid dog	Triangular distribution: minimum 0·00, mode 0·05, and maximum 0·10	Cleaveland et al,[10] Knobel et al,[11] and Fèvre et al[23]
Probability of an individual receiving anti-rabies vaccination if bitten by a suspected rabid dog (point estimate)	0·7826	Community survey data
Probability of death (p_{death})	0·02031828	$P1 \times [(P2 \times P6) + (P3 \times P7) + (P4 \times P8) + (P5 \times P9)] \times (1-P10)$
Incidence of suspected rabid-dog bite (annual incidence)	69/337 808	Number of suspected dog bites in the surveyed population
At-risk population (Q)	1 379 750 000	Population of India (2022)
Number of human rabies deaths (95% uncertainty limit) in 1 year	5726 (3967–7350)	$(p_{death}) \times$ (annual incidence) $\times$ (Q)

Table 4: **Deaths due to human rabies estimated using the decision-tree probability model**

surveillance is crucial for guiding rabies control activities including monitoring health status of biting dogs if they involve several biting incidents or are suspected to be rabid, initiating field investigation to trace all human and animal contacts and assessing for vaccination. This one-health approach has been successful in Latin American and southeast Asian countries,[2,22,23] and is vital for achieving the goal of Zero by 30 in India.

Mass vaccination of dogs is crucial for rabies elimination. Countries such as Mexico, Sri Lanka, and Bangladesh have successfully reduced human rabies mortality through consistent annual mass dog vaccination campaigns.[23–25] In India, dog vaccination is done alongside the Animal Birth Control (ABC) programme, but data on dog vaccination coverages are scarce, and implementation of the ABC programme is suboptimal.[26] High rabies positivity (75% during 2017–22) in suspected rabid dogs and low (50%) vaccination coverage in pet dogs underscore the need to improved dog vaccination coverage. Only a few smaller states, such as Goa and Sikkim, have achieved high dog-vaccination coverage resulting in reduced animal rabies positivity.[27,28] Given India's diversity, national campaigns are challenging and resource intensive. In view of this, the national action plan recommends that states estimate dog population in their respective areas and identify hotspots for conducting mass dog vaccination for 3 years with a coverage of 70% in those identified areas by local bodies, such as municipalities and municipal corporations and Panchayats.

Our study had certain limitations. First, the bite history of the family members was provided by an adult household member available during the survey, potentially missing bites among absent members or milder bites. However, animal bite is a unique medical event and family members are more likely to remember it. Further, bite exposure for the last 1 year was taken for analysis and hence missing bite exposure might be minimal and not affect the overall estimate. Additionally, recalling the number of vaccine doses taken might have been challenging, potentially underestimating the coverage by doses. We compared the number of doses received among the bite victims who had a documented proof and those with recall. The coverage by receipt of at least three doses was similar between those having and not having documentation of vaccination (appendix p 17). Second, we used a decision tree and probability model to estimate deaths. This model does not account for delays in receipt of ARV and rabies immunoglobulin. Our survey identified five deaths due to human rabies in the past 5 years (incidence 0·29 per 100 000 per year), roughly translating into 5000 deaths nationally, aligning with the estimate of our model. Third, rabies-positivity data among suspected rabid dogs were obtained from six laboratories catering to 12 states, with the number of samples tested ranging between one to 1000 in different states. Some states, especially in the eastern region of India, were not testing dog samples for rabies or data were not made available. Given that most of the data reported were from reference laboratories, rabies positivity might be overestimated. To account for this, sensitivity analyses were done and the number of deaths estimated assuming different scenarios were similar. Further, an expert group meeting using the Delphi technique was held among the academic and field veterinarians of India and the animal positivity data were validated before using them in the model. Lastly, we used Tepsumethanon's criteria to classify a bite as a suspected rabid-dog bite. Only dogs not monitored for 10 days or those killed within 10 days were classified using this criterion. In such instances, bite victims had a narrow window period to observe the health status of the dog. This short time period could have led to the underestimation of the incidence of suspected rabid-dog bites. However, only 30% of bites were classified using Tepsumethanon's criteria (appendix p 13) and the rest were decided on the basis of the living status of the dog.

In conclusion, although there was a significant decline in rabies deaths over the past two decades, the programme needs to intensify actions towards elimination of dog-mediated rabies by 2030. Adopting a focused one-health approach by integrating human and animal surveillance, ensuring timely administration of a full course of PEP, and accelerating dog vaccination across the country are crucial steps towards this goal.

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JWVT, MVM, and SD did the literature search. JWVT, MVM, NSK, and SD did the study design. JWVT, MVM, NSK, SE, DSR, SAK, AKS, AM, BS, DG, MM, NV, PS, RKS, RS, SMK, SB, TR, VVY, AkS, AsS, BVT, DRP, MMR, MT, NVS, PG, PJ, SV, ShD, SKP, VP, AGAR, DC, AD, AS, CP, SJ, SKI, MR, did the data collection. JWVT, MVM, NSK, SD, SE, and RS did the data analysis. JWVT, MVM, NSK, SE, DSR, SAK, AKS, AM, BS, DG, MM, NV, PS, RKS, RS, SMK, SB, TR, VVY, AdS, ASd, BVT, KP, MMR, MT, NVS, PG, PJ, SV, ShD, SKP, VP, AGAR, DC, AD, AS, CP, DHA, MKS, SJ, and MR, did the project management. JWVT, MVM, NSK, SD, and SE did the data interpretation. JWVT, MVM, SD, and SE accessed and verified the data. JWVT, MVM, NSK, and SD wrote the first draft of the manuscript. All authors approved the final draft of the manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

All key anonymised individual participant data collected during the study, along with a data dictionary, and excluding data on costs incurred for post-exposure prophylaxis (which will be part of a separate manuscript) are available upon request to the corresponding author, after approval of a proposal with a signed data access agreement.

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