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A Scoping Review of the Effectiveness of Control Interventions of Human and Canine Rabies in an Effort to Rationalise the One Health Approach

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Abstract

According to the World Health Organization (WHO), rabies is one of the 18 neglected tropical diseases, together with dengue, leprosy, and trachoma, among others. Despite being a vaccine-preventable disease, the latest estimate of annual human rabies mortality from a 2015 study is as high as 59,000 throughout 150 countries. In human rabies, more than 95% of the cases are due to dog bites, making the elimination of canine rabies a global priority by fighting the disease at its animal source. World Health Organization (WHO), World Organization for Animal Health (OIE), Food and Agriculture Organization (FAO) of the United Nations, and the Global Alliance for Rabies Control (GARC) have warranted the One Health framework with the objective of complete eradication of dog-related human rabies by the year 2030. In an effort to rationalise the One Health approach, this scoping review found 17 studies on assessing the effectiveness of control interventions of human and canine rabies. Different strategies were implemented based on the endemicity of rabies in a particular country. Overall, the combined strategies using the One Health approach, which allows effective participation and communication between different agencies, have shown promising results in reducing rabies cases. These strategies will hopefully realise the goal in the Global Strategic Plan to achieve zero canine-mediated human rabies death by the year 2030.

Keywords: Rabies, Effectiveness, One health, Control and Intervention

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Introduction

According to the World Health Organization (WHO), rabies is one of the 18 neglected tropical diseases, together with dengue, leprosy, and trachoma, among others (World Health Organization (WHO), 2020a). Despite being an ancient vaccine-preventable zoonotic disease, the latest estimate of annual human rabies mortality could still be as high as 59,000 across 150 countries around the globe (Hampson et al., 2015), (World Health Organization (WHO), 2020c). Although a preventable disease, it is generally fatal following the development of clinical signs of rabies (Centers for Disease Control and Prevention (CDC), 2019). In human rabies, more than 99% of the cases are due to dog bites (World Health Organization (WHO), 2020c), making the elimination of canine rabies a global priority by fighting the disease at its animal source.

In view of this, a quadripartite anti-rabies alliance between World Health Organization (WHO), World Organization for Animal Health (OIE), Food and Agriculture Organization (FAO) of the United Nations, and the Global Alliance for Rabies Control (GARC) have warranted the One Health framework with the principal goal of complete eradication of dog-related human rabies by the year 2030 (Lavan et al., 2017). The One Health initiatives acknowledge that the health of humans and animals together with the environment are highly interrelated. Built on five pillars, the action plan involves a collaborative strategy that combines sociocultural, technical, organisational, political, and resource-oriented aspects. It notably calls for three key actions; (1) to make human vaccination and immunoglobulin affordable, (2) to ensure timely treatment for bite victims, and (3) to implement mass vaccination campaigns for dogs in at-risk areas.

In this paper, we designed a scoping review of literature to examine the published evidence available on the effectiveness of human and canine rabies interventions in an effort to rationalise the One Health approach. The focus questions include the following:

1) What are the rabies control and prevention strategies being implemented globally?
2) What is the best practice for rabies control and intervention strategy?
3) Which of these has been shown to be effective, for different levels of rabies-risk setting?

Methods

Our review methodology adopts the 2005 framework as developed by Arksey and O'Malley (Arksey & Malley, 2005) constituting the following five essential components: (1) developing research questions, (2) identifying the relevant studies, (3) selecting the studies, (4) charting the data, and (5) gathering, summarising, and reporting the results.

Search strategy

A comprehensive electronic search through Medline and Centre for Review and Dissemination (CRD) databases was done to identify the relevant studies in the past five years. For the Medline database, we set the search-field descriptor in the PubMed search as MeSH and Text Word and we assigned search terms including "rabies [MeSH]" AND "vaccination [MeSH]" AND "cost-benefit [Text Word]". For the CRD database, the search term included "rabies" AND "effectiveness" OR "vaccination". Additional key studies were identified via other sources like the reference lists and hand searched using the Google Scholar search engine.

Study selection

Only peer-reviewed articles published in academic journals from 2015 to 2020 were considered. The identified studies were then selected for review only if they fulfilled the following set of eligibility criteria:

1) The study population must be dogs or humans or both.
2) The interventions considered include canine immunisation or post-exposure prophylaxis (PEP) treatment or pre-exposure prophylaxis (PrEP) for humans.
3) The result of study includes the effectiveness or cost-effectiveness of the control strategies considered.

Rabies studies on other wildlife species such as skunks, racoons, and foxes were not included in the review. Non-English articles, guidelines, blueprints, systemic reviews, anecdotal reports, pre-prints as well as other grey literature were excluded. Effectiveness and efficacy studies that solely focused on improving intervention performance, such as immune response, vaccine quality, and potency regarding clinical trials, as well as studies that only addressed surveillance and monitoring type interventions, were also excluded in the review.

Data charting

Two authors (NA and RS) independently extracted and analysed the data in all the studies selected for the final review. Descriptive data on the study country and population, aim and methods, types of intervention and control strategies, as well as the key findings for each study were collated and recorded. All discrepancies were resolved by consensus.

Results

Initial search across the two databases identified a total number of 36 studies, with 33 studies from the MEDLINE database, and the remaining three were from the Centre for Reviews and Dissemination (CRD) database. Two studies were removed due to duplication, leaving 34 studies subjected to the record screening of titles. From the title screening, eight studies did not target the dog or human population, while another two studies did not address rabies prevention and controls directly and were therefore excluded. Six additional articles were included via hand-search of the key terms in the Google Scholar search engine or chosen from the reference lists. A total of 30 studies were then further screened in our full-text eligibility assessment, whereby 13 articles did not meet our inclusion criteria. Two studies were in French and Chinese languages, another two publications were clinical trials, and the remaining did not have the outcomes of interest. As a result, 17 studies have met our inclusion criteria and so included in our final review, as seen in the flowchart in Figure 1 detailing the study selection. Table 1 presents the descriptive data of the studies extracted for our review.

Study characteristics

Around 47% of the studies(Borse et al., 2018; Hudson et al., 2019; Jeon et al., 2019; Laager et al., 2018; S. Musaili & Chepkwony, 2020; Taib et al., 2019; Wei et al., 2018; Yoder et al., 2019) included in our review were publications from the past three years while the remaining percentage (Bilinski et al., 2016; Dumas et al., 2015; Ferguson et al., 2015; Fitzpatrick et al., 2016; Mindekem et al., 2017; Muthiani et al., 2015; Velasco-Villa et al., 2017; E Wera et al., 2017; Ewaldus Wera et al., 2017) were published from the year 2015 to year 2017. Six studies (35%) were concerned on rabies in the continent of Africa; two in Chad (Mindekem et al., 2017; Yoder et al., 2019) one in Mali (Muthiani et al., 2015), one in Kenya (S. Musaili & Chepkwony, 2020), one in Tanzania (Bilinski et al., 2016) and one study in East Africa (Borse et al., 2018). Another four studies (23%) considered rabies in South East Asia; two in Indonesia (E Wera et al., 2017; Ewaldus Wera et al., 2017) one in Philippines (Ferguson et al., 2015) and one in Malaysia (Taib et al., 2019). In one study, the focus was on rabies in the Western Hemisphere region (Velasco-Villa et al., 2017) including North America, Central and South America and the Caribbean. A single study was conducted each for rabies in Australia (Wei et al., 2018), China (Laager et al., 2018), India (Fitzpatrick et al., 2016), France (Dumas et al., 2015) and in Latin America (Jeon et al., 2019). However, one study (Hudson et al., 2019) did not specify its study country as the researchers only simulated hypothetical scenarios.

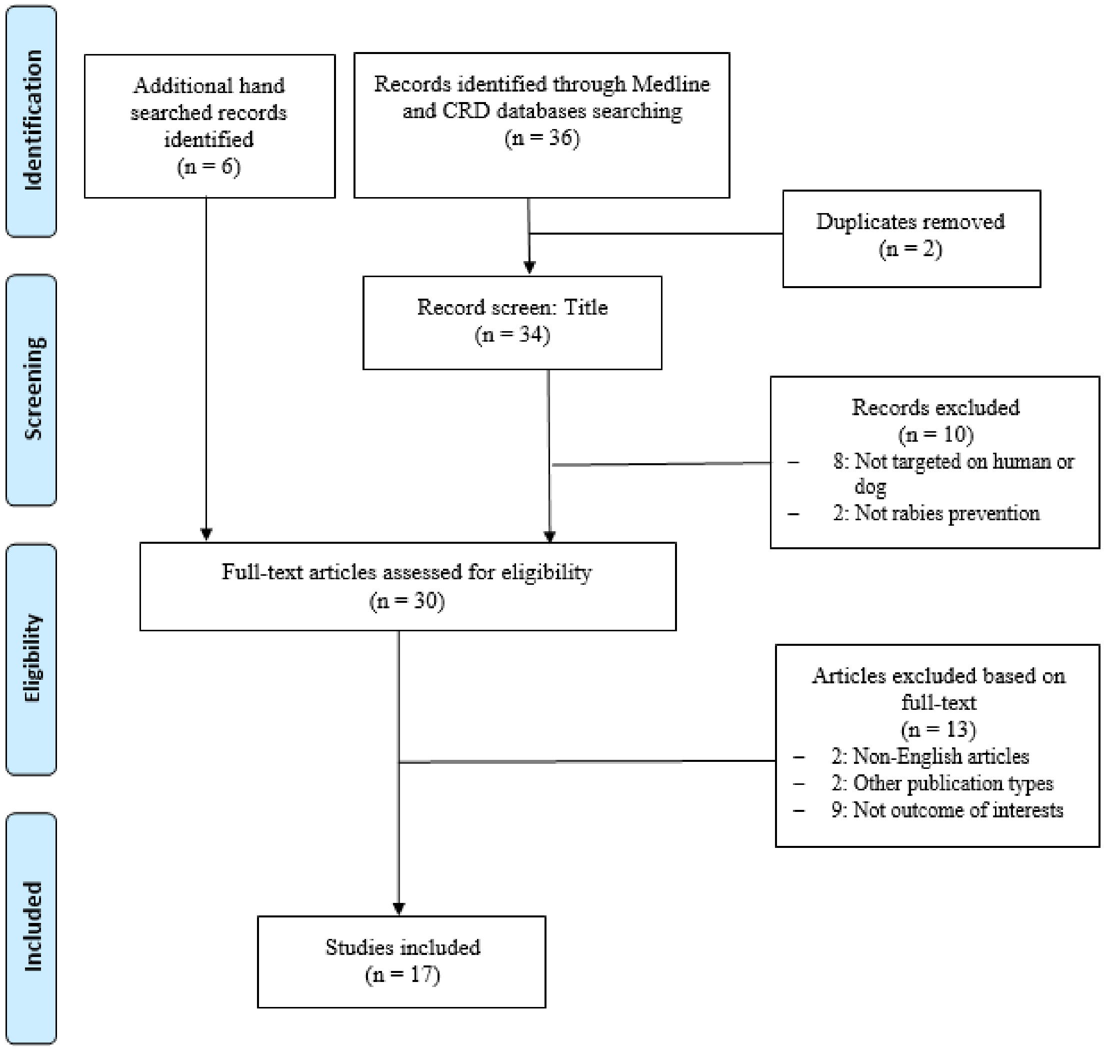

Figure 1: Flowchart of the study selection

In regards to the study objectives, ten studies (70%) aimed at evaluating or reviewing the effectiveness of different control and intervention strategies in human and canine rabies while the other 30% (Bilinski et al., 2016; Borse et al., 2018; Dumas et al., 2015; Fitzpatrick et al., 2016; Mindekem et al., 2017; E Wera et al., 2017; Ewaldus Wera et al., 2017) aimed at estimating the cost-effectiveness of rabies interventions. Almost all of the studies examined dog vaccination but other rabies control strategies such as public education, the combined use of dog vaccination and contraceptives, dog culling, human post-exposure prophylaxis (PEP), oral rabies vaccine (ORV), and surgical sterilization of dogs were considered as well.

Effectiveness evaluation

The evaluation of rabies intervention effectiveness was considered at different levels of rabies-risk (endemic, epidemic, and rabies-free). Although the endemic setting was the focal point in most literatures, three studies (Dumas et al., 2015; Hudson et al., 2019; Wei et al., 2018) have analysed the effectiveness of rabies prevention and control strategies in a rabies-free scenario. There were 13 studies utilising mathematical models to simulate disease transmission; nine

(Bilinski et al., 2016; Fitzpatrick et al., 2016; Hudson et al., 2019; Mindekem et al., 2017; S. Musaili & Chepkwony, 2020; E Wera et al., 2017; Ewaldus Wera et al., 2017; Yoder et al., 2019) of which used a compartmental, deterministic model, one (Dumas et al., 2015) used decision-tree model, while another two(Taib et al., 2019; Wei et al., 2018) used individual- and agent-based models. The remaining studies (Ferguson et al., 2015; Jeon et al., 2019; Laager et al., 2018; Muthiani et al., 2015; Velasco-Villa et al., 2017) primarily used statistical analysis on available data in evaluating the intervention effectiveness.

Six studies (Bilinski et al., 2016; Ferguson et al., 2015; Fitzpatrick et al., 2016; Muthiani et al., 2015; Wei et al., 2018; E Wera et al., 2017) examined dog vaccination alone including small and large scale mass dog vaccination campaigns, one study (Dumas et al., 2015) focused solely on human PEP as the prevention and control strategy, whereas other studies have addressed the use of alternative interventions such as oral rabies vaccine (ORV) together with mass parenteral vaccination, or the combination of dog vaccination and human PEP, culling or surgical sterilization as well as public health education.

Table 1: Description of selected studies included in the review. (n = 17)

No.	Author/ Year	Study country/ population	Rabies-risk level	Aim and methods	Interventions considered	Key findings
1	Musaili JS et al. (2020) (Musaili & Chepkwony, 2020)	Country: Makueni county, Kenya. Study population: Dogs.	Endemic	Aim: To study the influence of public health education as one of the control measures of canine rabies elimination in Makueni. Methods: Numerical simulation using a deterministic, compartmental model that captures the rabies transmission dynamics among dogs in Makueni.	Public health education on the importance of canine pre- and post-exposure prophylaxis with emphasis on the concept of responsible ownership.	Public health education on the importance of canine pre- and post-exposure prophylaxis with emphasize on the concept of responsible ownership produced a significant decrease in the number of rabid dogs in Makueni.
2	Hudson EG et al. (2019) (Hudson, et al., 2019)	Country: Northern Peninsula Area (NPA), Queensland	Rabies-Free.	Aim: To assess the effectiveness of several vaccination programs in	Dog vaccination	In a rabies-free NPA, a random vaccination strategy is favourable as opposed to a non-vaccination strategy.

		, Australia. Study population: Dogs.		terms of different dog roaming patterns in NPA, Queensland. Methods: An agent-based, stochastic model is developed which simulates outbreaks among the population of free-roaming domestic dog in NPA.		A random non-targeted vaccination coverage of 40% is the most efficient in the context of NPA. However, as compared to a random vaccination strategy with the same percentage of coverage, a 40% vaccination coverage targeting more on roaming dogs was more effective in decreasing the size and period of epidemic.
3	Jeon S et al. (2019) (Jeon et al., 2019)	Country: Hypothetical scenario. Study population: Dogs, humans.	Rabies-Free.	Aim: To evaluate the level of vaccination needed to prevent the re-establishment of dog rabies in a post-elimination setting. Methods: A modified version of RabiesEcon, which is a deterministic mathematical model to simulate different rabies reintroduction scenarios.	Dog vaccination, human PEP	To prevent the reintroduction of dog rabies in a post-elimination setting, it is crucial to vaccinate the free-roaming dog group with coverage of at least 38% to 56%. Rabies-free countries are at risk of reintroduction if dog movement control and surveillance system are not fortified post-elimination.
4	Yoder J et al. (2019) (Yoder et al., 2019)	Country: Latin America. Study	Endemic.	Aim: To study the influence of dog rabies vaccination on the aspects of	Dog vaccination, human PEP.	As the usage of human PEP increases by 10%, human rabies deaths decrease by 7%, but

		population: Dogs, humans.		human deaths due to rabies, bites reporting, and human PEP. Methods: A multivariate regression analysis is performed over annual rabies-related data from 1995 to 2005 across seven different Latin American countries.		when canine vaccination is increased by 10%, the usage of PEP can be reduced by 2.8%. Emphasis is on the importance of mass dog vaccination, public education, treatment accessibility, and clinical algorithms to avoid wastage of human PEP.
5	Abdul Taib NA et al. (2019) (Taib et al., 2019)	Country: Sarawak State, Malaysia. Study population: Dogs, humans.	Epidemic.	Aim: To determine the parameter with the most impact on Sarawak rabies transmission dynamics. Methods: Model simulation using a deterministic model to simulate rabies transmission among dogs and dog-to-human in Sarawak.	Dog vaccination, dog population management.	The ongoing outbreak can be managed effectively by increasing dog vaccination coverage and reducing the number of newborn puppies while culling is ineffective for long-term rabies elimination. Culling is an ineffective method for population control.
6	Laager M et al. (2018) (Laager et al., 2018)	Country: N'Djamena, Chad Study population: Dogs	Endemic	Aim: To evaluate the effects of dog heterogeneity at individual levels and examine the risk of re-establishment over different	Dog vaccination, Oral Rabies Vaccine (ORV).	70% coverage of dog vaccination would prevent major outbreaks. Targeted vaccination on the population of highly connected roaming dogs would be a

				vaccination coverage. Methods: An individual-based contact network model of dog rabies transmission in N'Djamena is developed.		more effective vaccination strategy as compared to a random vaccination strategy. Oral vaccination would be an effective method to immunise these highly connected roaming dogs.
7	Wei XK et al. (2018) (Wei et al., 2018)	Country: Guangxi Province, China Study population: Dogs, humans	Endemic	Aim: To advocate the vaccination of domestic dogs in rural China in order to reduce the number of human rabies cases significantly. Methods: A vaccination program model, applicable to rural China is developed and assessed.	Mass dog vaccination, dog surveillance, vaccinated dog monitoring, human rabies surveillance.	To control rabies in Guangxi, a rabies vaccination program has been successful demonstrated which involves several control strategies such as dog vaccination, dog surveillance and monitoring, as well as compiling and reporting statistics of human rabies cases.
8	Borse RH et al. (2018) (Borse et al., 2018)	Country: East Africa. Study population: Dogs, humans.	Endemic.	Aim: To estimate the cost-effectiveness of East African dog rabies vaccination programs. Methods: Model simulation using a spreadsheet tool, RabiesEcon, which incorporates a deterministic	Mass dog vaccination, human PEP and RIG, dog population management.	In a low disease transmission setting, mass vaccinating 20% (biennial) or 50% (annually) of the East African dog population is the most cost-effective. However, in a high transmission scenario, a 70% vaccination coverage is required to control the spread of rabies for a minimum of 20 years.

				model of dog-to-dog and dog-to-human rabies transmission.		
9	Velasco-Villa A et al. (2017) (Velasco-villa et al., 2017)	Country: Western Hemisphere. Study population: Dogs, humans .	Varies.	Aim: To review the available control strategies for canine rabies eradication within the Western Hemisphere. Methods: The necessary available information on the progress of canine rabies elimination from the Western Hemisphere is collated and extensively reviewed.	Mass dog parenteral vaccination, oral rabies vaccine (ORV), culling, immunocontraception, dog population management and surveillance.	In order to increase vaccination coverage, oral rabies vaccine (ORV) should be utilised to vaccinate free-roaming dog populations. Immunocontraception can be used as fertility control to manage free-roaming dog populations in Latin American countries. Canine rabies can be eradicated when dog herd immunity is maintained at above 70%, along with laboratory-based surveillance of rabies in dogs, domestic animals and wildlife, as well as heightened public awareness. Culling only when the number of human rabies exposures is high.
10	Mindekem R et al. (2017) (Mindekem et al., 2017)	Country: N'Djamena, Chad. Study population: Dogs, humans.	Endemic.	Aim: To evaluate the cost-effectiveness, defined as the cost per human exposure averted, of different intervention strategies in N'Djamena,	Dog mass vaccination, human PEP, and paramount One Health communication i.e. communication between human health and veterinary professionals.	The combined strategies of dog vaccination, human PEP and paramount One Health communication is more cost-effective as compared to the strategy of using PEP alone. In a resource poor setting, the cost of

				Chad. Method: Numerical simulation using a deterministic model capturing the dynamics of N'Djamena rabies transmission among dogs and dog-to-human and economic evaluation of the mass vaccination campaigns in N'Djamena.		PEP use will be significantly lowered when the One Health concept is efficiently applied.
11	Wera E et al. (2017) (Ewaldus Wera et al., 2017)	Country: Flores Island, Indonesia. Study population: Dogs, humans.	Endemic.	Aim: To conduct an economic evaluation when different mass vaccination strategies is applied in Flores Island. Methods: Numerical simulation using a deterministic model representing the dynamics of rabies transmission among dogs and dog-to-human in Flores Island to estimate the cost-effectiveness ratio of the alternative	Mass dog vaccination, human PEP.	The combined strategies of annual vaccination using a long-acting vaccine at 70% coverage together with human PEP could eliminate all human rabies deaths completely although at a slightly higher cost-effectiveness ratio.

				strategies for mass vaccination.		
12	Fitzpatrick MC (2016) (Fitzpatrick et al., 2016)	Country: Tamil Nadu, India. Study population: Owned dogs, stray dogs.	Endemic.	Aim: To assess the cost-effectiveness for different control strategies of rabies in Tamil Nadu. Methods: Numerical simulation using a deterministic model of rabies transmission utilising data on human rabies and canine demography in Tamil Nadu.	Dog vaccination (owned dog, stray dog).	Focus should be more on vaccinating at least 13% of the stray dog population in Tamil Nadu as it would be more cost-effective in lowering the number of human rabies cases by up to 90%.
13	Bilinski AM et al. (2016) (Bilinski et al., 2016)	Country: Ngorongoro and Serengeti, Tanzania. Study population: Dogs, wildlife, and humans.	Endemic.	Aim: To evaluate the cost-effectiveness of several rabies canine vaccination campaigns with different coverage and frequency. Methods: Numerical simulation using a deterministic model that incorporates the dynamics of dog, wildlife and human populations.	Mass dog vaccination campaign.	The study emphasises on campaign frequency, rather than coverage. When risk of rabies reintroduction is low, semi-annual vaccination campaigns are the most cost-effective to control the disease spread.

14	Wera E et al. (2016) (E Wera et al., 2016)	Country: Flores Island, Indonesia Study population: Dogs.	Endemic.	Aim: To evaluate the cost-effectiveness of alternative mass vaccination strategies for rabies control in Flores Island. Methods: Numerical simulation using a deterministic model that incorporates the dynamics of rabies transmission in Flores Island.	Mass dog vaccination campaign.	The implementation of an annual mass dog vaccination campaign with 70% coverage using a long-acting vaccine can reduce the duration of outbreaks thus the strategy would be the most cost-effective in the context of Flores Island.
15	Dumas FR et al. (2015) (Dumas et al., 2015)	Country: France. Study population: Humans.	Rabies-free.	Aim: To conduct an economic evaluation of PEP strategies following dog bite exposure in very low rabies risk settings. Methods: A decision-tree model is developed simulating the trajectory of bite victims in French cities seeking PEP treatment following dog bite exposure.	Human PEP and RIG.	Regardless of the category of exposure, the administration of human PEP is not the most cost-effective method and thus not preferable in a setting with very low risk of rabies.
16	Muthiani Y et al. (2015) (Muthiani et al.,	Country: Bamako, Mali. Study	Endemic.	Aim: To estimate the achieved coverage of a small-scale	Small-scale central-point dog vaccination campaign.	The achieved coverage of fixed-point vaccination campaign in Bamako was low

	2015)	population: Dogs, humans.		dog mass vaccination campaign in Bamako and to determine weak key parameters for intervention effectiveness. Methods: Following the vaccination campaign, household survey and a transect survey within the vaccination zone were conducted simultaneously. The household and transect-survey data were fitted to a Bayesian model in order to estimate the overall vaccination coverage. An effectiveness-model framework was developed to estimate effectiveness parameters of interventions.		(only 17%) which could be due to low engagement by dog owners. Lack of information and dog aggressiveness affect intervention effectiveness. To increase the knowledge within the society, a stakeholder approach should be taken in which the community itself is proactive in every step of the process from the initial planning up to implementation stage of the campaign. A vaccination campaign combining both fixed point and house-to-house vaccination strategy could mitigate the problem of handling aggressive dogs.
17	Ferguson EA et al. (2015) (Ferguson et al., 2015)	Country: Region VI (Western Visayas), Philippines. Study population: Dogs.	Endemic, rabies-free.	Aim: To study the impact of spatial heterogeneity in vaccination coverage and human-mediated dog movements for the	Mass dog vaccination campaign.	The effectiveness of mass vaccination campaigns could be reduced significantly due to spatial heterogeneity in vaccination coverage even when the overall coverage

				elimination of endemic canine rabies by mass dog vaccination in Region VI of the Philippines (Western Visayas). Methods: A spatially-explicit canine rabies transmission model is developed which incorporates dog movement and vaccination coverage scenarios in Region VI.		is high. The problem of heterogeneity can be mitigated through vaccine redistribution. Long-distance dog movement will increase the risk of rabies reintroduction into a rabies-free area. Thus, an effective surveillance and dog movement regulations will be critical at this post-elimination setting.

Discussion

The World Health Organization (WHO) has asserted that annual mass canine vaccination with an optimal threshold of 70% coverage would be the most cost-effective rabies control strategy (WHO, 2020b). Five studies (Borse et al., 2018; Muthiani et al., 2015; Taib et al., 2019; Velasco-Villa et al., 2017; Ewaldus Wera et al., 2017) have also highlighted the importance in sustaining a minimum of 70% dog vaccination coverage to induce herd immunity, which aligns with WHO's recommended guideline for canine rabies control. Furthermore, in an effort to manage the stray dog population with zero rabies immunity, two studies (Laager et al., 2018; Velasco-Villa et al., 2017) considered the use of baits laced with oral rabies vaccines (ORV). Laager (Laager et al., 2018) suggested a targeted vaccination strategy on a highly-connected roaming dogs with 70% coverage to eliminate endemic rabies.

Five studies (CDC, 2019; Jeon et al., 2019; Laager et al., 2018; S. Musaili & Chepkwony, 2020; WHO, 2020c) considered shifting the focus on vaccinating free-roaming stray dogs as the most effective means to control rabies both in a endemic setting or in a rabies-free area as a preventive measure. However, in a very low rabies risk setting, researchers (Hudson et al., 2019; Jeon et al., 2019) have found that a vaccination coverage of less than the WHO-recommended 70% is sufficient to maintain a rabies-free status. As compared to a random vaccination strategy, a vaccination strategy of 40% coverage in NPA, Queensland targeting more on free-roaming dogs rather than the easily accessible non-roaming dogs would be more effective in preventing rabies incursion into the area (Hudson et al., 2019). These findings were also supported by another study (Jeon et al., 2019) which considered a simulated rabies-free post-elimination scenario in which a vaccination coverage of 38% to 56% of free-roaming dogs was found to be the most effective prevention measure.

Two studies (Ferguson et al., 2015; Jeon et al., 2019) have stressed the importance of dog surveillance in a post-elimination setting in order to prevent rabies re-establishment. An economic evaluation conducted by Dumas (Dumas et al., 2015) showed that, in terms of the rabies-free France, the human PEP treatment administered to bite victims indeed accumulated significant unnecessary costs, and is therefore not preferable regardless of the category of exposure.

In eradicate canine rabies in an endemic setting, Yoder (Yoder et al., 2019) emphasized on the combined strategy of mass dog vaccination and increasing public awareness and treatment accessibility, as well as having a better clinical algorithm to reduce the wastage of the costly, unnecessary PEP use. One study in Sarawak has found that the more effective strategy to manage the ongoing rabies outbreak would be to increase the dog vaccination coverage and to lower the dog birth rate (Taib et al., 2019) while culling is an ineffective method to stop the spread of rabies according to two studies (Taib et al., 2019; Velasco-Villa et al., 2017).

Additionally, two studies (Bilinski et al., 2016; Borse et al., 2018) have indicated that in a low-risk of rabies reintroduction, conducting a semi-annual vaccination campaign would be the most cost-effective to control the disease spread. According to Borse (Borse et al., 2018), dog vaccination coverage of 70% or above to halt the spread of rabies for at least 20 years in a high disease transmission scenario. However, in a low transmission scenario, vaccinating 20% semi-annually or 50% annually of the East African dog population will be most cost-effective.

Velasco-Villa (Velasco-Villa et al., 2017) suggested the use of ORV to immunise the free-roaming dogs especially in hard-to-reach places during mass parenteral vaccination campaigns and the use of immunocontraception to control the population of free-roaming dogs. Furthermore, the feasibility of canine rabies elimination can only be achieved when dog herd immunity is maintained at above 70%, along with sustained laboratory-based animal surveillance, as well as heightened public awareness on rabies education and the practice of responsible pet ownership.

Wei et al., 2018 stated that a control strategy involving mass dog vaccination, dog surveillance and monitoring, as well as human rabies case reporting can effectively reduce the spread of rabies from dogs to humans and successfully control endemic rabies in Guangxi. A study done by Fitzpatrick (Fitzpatrick et al., 2016) recommended vaccinating more of the stray dog population to control human rabies death while Musaili (S. Musaili & Chepkwony, 2020) emphasized the importance of public health education regarding both pre- and post-exposure prophylaxis for dogs as well as the practice of responsible dog ownership. According to

Muthiani (Muthiani et al., 2015), to increase the public awareness on mass dog vaccination, a stakeholder approach concerning a proactive participation of the community along every step of the process from the initial planning up to the implementation stage of the vaccination campaign should be integrated.

Two studies (Fitzpatrick et al., 2016), (E Wera et al., 2017) have highlighted the effectiveness of using long-acting vaccines for dog immunisation as compared to short-acting vaccines. Based on Wera (E Wera et al., 2017), implementing mass dog vaccination campaign annually with a 70% vaccination coverage using a long-acting vaccine produced shorter outbreak duration. A follow-up study in 2017 found that human rabies in Flores Island, Indonesia can only be eradicated with the use of combined strategies involving the long-acting vaccine at 70% coverage together with human PEP (Ewaldus Wera et al., 2017). Bilinski (Bilinski et al., 2016) also stated that less frequent vaccination campaigns would be optimal when risk of rabies reintroduction is low.

The estimated cost-effectiveness by Mindekem (Mindekem et al., 2017) is significantly higher for the control strategy involving combination of canine vaccination, human PEP and One Health communication as compared to the strategy of using PEP alone. Furthermore, reducing spatial heterogeneity by closing the gaps in vaccination coverage via vaccine redistribution could be a more effective mass vaccination campaign strategy as stated by Ferguson (Ferguson et al., 2015) while in a post-elimination setting, effective dog movement surveillance is important to prevent rabies reintroduction.

Conclusion

In an effort to rationalize the One Health approach, this scoping review found 17 studies on assessing the effectiveness of rabies interventions and control strategies. Different strategies were implemented based on the endemicity of rabies in that particular country. Among the successful strategies were public education, the practice of responsible dog ownership, human-animal surveillance system, targeted dog vaccination, control of free roaming population, as well as a decentralised network for animal control, surveillance and vaccination. Furthermore, the stakeholder approach needs to be strengthened which involves community-level collaboration when planning and implementing intervention programs. Overall, the combined strategies using One Health approach which allows effective participation and communication between different agencies including human health and veterinary professionals, among others have showed promising results in reducing rabies cases. The strategies will hopefully able to realize the goal in the Global Strategic Plan to achieve zero canine-mediated human rabies death by the year 2030.

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