Rabies burden in Côte d'Ivoire

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Highlights

- The current study is the first estimate of the burden and financial cost of rabies in Côte d'Ivoire. The results will provide information needed for designing an adequate rabies control strategy. This information is fundamental towards achieving the goals set by the WHO and OIE for the elimination rabies by 2030. It also highlights the benefits that can be expected for the country if rabies could be eliminated.
- The data was collected from a cross-sectional survey of 8004 households, of which 4002 were in the Department of Bouaké and 4002 in the Department of San Pedro. This data was collected in both rural and urban areas. Further data was collected from Human Rabies control centres and from the respective veterinary services

Abstract

Background: In Côte d'Ivoire, just as in the majority of developing countries, rabies cases are underestimated. The official data are based on passive surveillance studies which cannot provide true estimates. Therefore, the economic and health burden of rabies is underestimated. To be able to better estimate the true burden of rabies, this study looked at surveillance data of bite records and household survey.

Methodology: The data was collected from a cross-sectional survey of 8004 households, of which 4002 were in the Department of Bouaké and 4002 in the Department of San Pedro.

Further data was collected from Human Rabies control centres and from the respective veterinary services. We estimate the burden of rabies through data from the bites surveillance records. Human deaths from rabies were estimated using a series of probability steps to determine the likelihood of clinical rabies in a person after being bitten by a suspected rabid dog. Monte Carlo simulations of a series of interconnected probabilities were used to estimate the rabies burden in the country.

Results: The number of deaths from rabies was estimated at 637deaths per year [95% CI 442-849] and human mortality from rabies was estimated at 2.61 per 100'000 [95% CI 1.81-3.56], which represents 24-47 times more cases than the official data. Deaths due to rabies are responsible for 23252 Disability Adjusted Life Years (DALY) lost each year [95% CI 16122-30969]. The estimated annual cost of rabies is 40.15 million USD [95% CI 27.8-53.4]. Overall, 99% of the cost was due to premature deaths. The cost of post-exposure prophylaxis was estimated at 1.6 million USD and represented 1% of the overall cost of rabies.

Conclusion: This study highlights the underreporting of rabies cases by the official health information system in Côte d'Ivoire and the annual financial losses related to rabies are equivalent to the estimated cost of the elimination of rabies by 2030. Thus, investing in the fight against in Côte d'Ivoire will be cost effective.

Introduction

Rabies is a viral zoonotic disease responsible globally for an estimated 59000 human deaths and over 37 million disability-adjusted lost every year (Hampson et al. 2015). Transmission of rabies by dogs is responsible for up to 99% of human rabies cases in endemic regions (WHO, 2018).

Rabies is almost invariability fatal once clinical signs appear, as result of acute progressive encephalitis. Rabies occurs mainly in underserved populations, both rural and urban, and has been documented for more than 4000 years (Tarantola, 2017).

The annual cost for the control and prevention of rabies in Asia and in Africa has been estimated to be more than $US 500 million, with the majority of these expenditures related to Post-Exposure Prophylaxis (PEP) (Hampson et al. 2015).

Most cases occur in Africa and Asia, with approximately 40% of cases in children aged <15 years.

Mass vaccination campaigns targeting dogs constitute the principal strategy for rabies control by interrupting rabies virus transmission to humans and other mammals (Rupprecht, 2017).

Data related to the impact of rabies on the health and economies are unknown or underestimated in most low-income countries, particularly countries in Africa (Cleaveland et al. 2002; Fevre et al. 2005).

In some countries, such as Tanzania, the estimated incidence of rabies mortality was 10 to 100 times higher than the reported official incidence (Maganga et al. 2013). Rabies remains underreported in much of Africa in official rabies mortality statistics for animals and humans, because of poor health seeking behaviour and lack of knowledge about the disease in the general population and among health professionals (Knobel et al. 2005). Numerous studies in Asia and

Africa have attempted to estimate the burden of rabies using a range of methods such as probabilistic decision trees (Ly et al. 2009; Tenzin et al. 2011), extensive community surveys (Hossain et al. 2012; Jemberu et al. 2013), and passive surveillance (2008). These studies have all revealed that rabies mortality is much higher than official figures suggest.

In Côte d'Ivoire, the National Institute of Public Hygiene records an average of 18 human cases of rabies per year and an average of 12000 bite case victims (Ministère de la santé et de l'Hygiène Publique, 2017). Also, on average ten cases of animal rabies are recorded annually by the Veterinary Services (Ministère des Ressources Animales et Halieutiques, 2017). However, a recent household survey revealed 48,000 cases of animal bites per year (Kallo et al., 2020) – a number much higher than the officially notified cases. This study highlights the disparities between officially recorded and actual rabies deaths. Like most developing countries, it is clear that the burden of rabies in Côte d'Ivoire is underestimated.

There are considerable challenges in Côte d'Ivoire to provide universal access to rabies post-exposure intramuscular prophylaxis. These challenges include high number of bite victims who are lost to follow-up (64%) (Tetchi et al., 2020), vaccine out of stock, high costs of each vaccine dose, high costs of patient transport related to the number of doses administered and the distance of the health structures (Tiembré et al., 2011). Faced with these difficulties, it is important to seek other alternatives that can reduce the direct and indirect cost of care for bite victims.

In addition, the search for adequate funding and the necessary support from political decision-makers cannot succeed without advocacy based on reliable data reflecting the real economic and health impact of rabies.

Bypassing the established passive surveillance reporting system with its presumed underreporting, our study aims to estimate the true burden of rabies by extrapolating data from the surveillance of bites recorded in the departments of Bouaké and San Pedro from 2016 to 2017, for the whole of Côte d'Ivoire.

Methodology

Study zone

We conducted a cross-sectional study of households in rural and urban areas in the departments of Bouaké and San Pedro, located in the center and the south-west of Côte d'Ivoire (Figure 1) from June 2016 to the end of 2017.

From each department, the main municipality was selected to represent an urban area, while the surrounding areas were classed as rural.

The human population of the two sites are 630′ 000 inhabitants for San Pedro and 680′ 000 inhabitants for Bouake (Recensement Général, 2014). These study sites were chosen because in San Pedro a high number of human cases were registered, with 10 cases between 2006 and 2015 (Ministère de la Santé et del'Hygiène Publique Vétérinaire, 2016), while Bouake had the highest number of dog bite victims in Cote d'Ivoire, with the most cases of animal rabies in 2015.

Data Collection

General data on the population across the different departments of Côte d'Ivoire were collected from the last census of habitat and populations (Recensement Général, 2014)

Three sources were used to collect data from the two study areas (Bouaké and San Pedro). First: The survey has taken place in two stages. The first involved the administration of a questionnaire to determine the incidence of exposures in the last six months, the socio-demographic and economic characteristics of the household, and their knowledge of rabies. The second involved the administration of a questionnaire for households reporting animal bites assessing characteristics of victims and biting animals, demand for care, access to PEP and cost.

To establish the necessary sample size for the household survey of dog bites, we assumed an animal bite incidence of 0.000276 per person-month (i.e. annual incidence = 0.0033) based on Frey (2013). The small number of reported bites (recall of dog bites in the last month) has several implications for the statistical analysis: i) the intra cluster correlation coefficient depends on the observed prevalence and is likely smaller than usual and ii) some statistical methods to account for cluster sampling exhibit a poor performance. Therefore, standard formulas for sample size calculation should not be applied in this context. Instead, we conducted a series of simulations to identify an appropriate sample size. We evaluated several statistical methods and identified one with confidence intervals close to the nominal values. Assuming a mean number of 5 household members in urban and 7 in rural areas, a total sample size of 6’000-12′000 households was a good compromise between statistical precision and logistic feasibility. Cluster sampling was done proportional to village size from existing census data to allow convenient extrapolation to the population level. This cross-sectional household study used cluster sampling with selection probability proportional to cluster size and stratified by rural/urban and study area. In urban areas, 99 geo-reference points were hazardly selected in each department. Of these, 40 points were randomly selected to reach the expected number of households. Investigations were conducted in 50 households for each geo point in the different cities. In the rural areas of each department, 46 villages were randomly selected using data from the last general population census (2014) of Cote d'Ivoire. Of the 46

villages, 40 were included, with 50 households randomly selected in each village. Each investigator was trained and obtained a Rabies Trainer Certificate. They were vaccinated against rabies, and then pre-tested the questionnaire in two of the selected sites. Following the pretest, the questionnaire was adapted and finalized. Each investigator was provided with a tablet for data entry and a spare battery. Three mobile phones, internet connection (wifi Pocket) and three motorcycles were provided for each team in the rural areas. A timetable was established for each team. In case a household could not be accessed for any reason, the following household was chosen. The reason was noted in the tablet data collection system.

In rural areas, villages were subdivided into five areas and each investigator had 10 households to investigate after identification of thestarting point by the team. Calculated number of steps was two in the rural areas. households are selection every second household.

In urban areas, from the list of 99 geo-points selected randomly the supervisor chose a starting point and most appropriate direction for the investigators. Calculated steps for households in the urban areas was three.

The household data was collected using the ODK platform. Interviews were conducted in French and if necessary in local language. The collected information was the number of people, ownership of dogs or cats, animal vaccination status, and reasons for non-vaccination of animals. We also collected information on bite victims: age, gender, help seeking, time to consultation and reasons for delay, as well as the place and circumstance of the bite incident, and the site and nature of the bite wound.

Second: Information on bite victims was collected at the level of the health structures in charge of managing PEP. This included personal characteristics of the victim, the circumstances of the bite, and the location of the injury and the administration of PEP. Third: Information registered with the veterinary services concerning the monitoring of biting animals and laboratory diagnosis by the direct immunofluorescence technique for animals suspected of rabies whose

brain samples were sent to the National Laboratory for Agriculture Development Support (LANADA). The demographic data used to calculate the sample size in each cluster and the estimated annual incidence and human mortality per 100'000 people due to rabies were derived from the general census of population of Côte d'Ivoire (Recensement Général, 2014).

Estimation of the burden of rabies

We adopted the decision tree probability model developed by Cleaveland et al. in Tanzania (Cleaveland et al., 2002), which was also used by Frey in Tchad and Knobel in Africa (Frey et al., 2013; Knobel et al.,2005) to estimate the rabies burden in Côte d'Ivoire. The model uses the product of bite incidence, the probability of being bitten by a rabid animal, the probability of receiving PEP, and the probability of developing rabies in the absence of PEP, to estimate human mortality due to rabies. The probability of access to PEP corresponds to the proportion of patients who have received at least one of rabies vaccine after having been bitten by a suspected rabid dog. A dog is considered suspected of rabies if: i) aggressive ii) free-roaming iii) disappeared after biting iv) died v) rabies symptoms with confirmation by a veterinarian vi) put under surveillance and considered as expressing rabid behavior.

The probability of a dog being rabid (P_1) corresponds to the proportion of dogs tested positive in the National Laboratory for Agriculture Development Support (LANADA) corrected for post sample bias:

$$P_{1\ corrected} = P_1*2/3+P_1*0.5*1/3.$$

The Monte Carlo simulation in Microsoft Excel™ has been used with the software Ersatz (www.epigear.com). It extends Excel with a range of probability functions that offer various statistical distributions, allowing for a Monte Carlo simulation with 10'000 iterations.

Human deaths are converted to disability adjusted life years (DALYs) lost. The economic estimates take into account the cost of rabies prevention and control which has several

components namely surveillance including laboratory diagnosis, use of rabies vaccine for pre and post exposure prophylaxis, immunoglobulins which were recently introduced in the project zone and the control of canine rabies through mass dog vaccination.

The burden of rabies was calculated using essentially the number of years of life lost (YLL). The total YLL due to rabies were estimated using WHO standard life table reference from the 2010 Global Burden of Disease Study (Murray et al., 2012). The following formula was used:

$$YLL = \sum_{x=0}^{x=L} dx(\mathrm{L} - \mathrm{x})$$

Where dx is the death at an age x and L is the potential age limit for life. We have chosen the estimated life expectancy of the population at birth as the age limit. The limit used in practice is between 60 to 85 years (Murray, 1994).

Financial cost

The loss of productivity assessment allowed us to estimate the financial cost of deaths from rabies based on the number of years of life lost (YLL). As described above, for each death due to rabies, YLLs are estimated from the age distribution of patients having died from rabies and the life expectancy of Ivorian population in 2017 which was 55,86 years (World Bank, 2020). Thus, the loss of income due to premature deaths is equal to the product of the YLL and the average annual per capita income of 2016 which was $1930 according to the World Bank Group (World Bank, 2017).

In Côte d'Ivoire, health providers apply the Zagreb and Essen PEP protocols. In the current study we considered the Zagreb protocol which is 4 doses of rabies vaccine on days 0 (2 doses), 7 (1 dose) and 21(1 dose). The Zagreb protocol includes two injections of vaccine on day 0, one in each thigh (deltoid).

The PEP-related costs were estimated based on the rate of 124 / 100’000 inhabitants (Baseline Survey estimate) multiplied by the price of one dose of rabies’ vaccine (8’000 Franc CFA or 18.40 USD), considering four doses per patient. In addition to the vaccine, the cost of rabies immunoglobulin (EQUIRAB) (25’000 Franc CFA or 46,1 USD) introduced by the project for the management category III bite was added to the total cost in 2017.

The additional costs, attributable to other expenditures, were estimated based on t the incidence of dog bites of 2 per 1’000 person years (Kallo et al., 2020). Of those, the proportion of care seekers (42%) was multiplied by the average additional cost paid by the bite victim (3263 Franc CFA or $ 5.81).

The cost of controlling canine rabies was essentially based on the cost of one PEP vaccine dose, the vaccination record and the vaccination cost. To obtain an estimate of the vaccination coverage at the national level, we used the data of the baseline survey (Kallo et al., 2020). Knowing the cost of immunization for a dog (5.38 USD) which is calculated from the sum of the cost of a vaccine dose (2.96 USD), the vaccination booklet (0.45 USD) and the injection cost (1.97 USD). We used the 2016 exchange rate of 1 USD = 543.30 FCFA by the World Development Indicators (World Bank, 2020).

Extrapolation

From the results in the study areas, an extrapolation was made at the national level from the incidence density (ID) of the deaths assuming a dynamic population in each zone; the incidence was estimated as follows:

$$ID = Nc \div P(\Delta t)$$

Where Nc is the number of new cases and P the population at risk in Bouaké and San Pedro, Δ t is the length of observation of the follow-up period in 2016 and 2017. Thus, the extrapolation at national level was obtained from the cumulative incidence estimated for Bouaké and San Pedro (ID Bouaké et San Pedro) multiplied by the population of Côte d'Ivoire in the estimated year of the RGPH 2014 described as follows:

$$ID = \frac{NC\ Bouaké\ and\ San\ Pedro}{\text{Population Bouaké and San Pedro } (\Delta \text{t})}$$

The formula below was used to estimate the population of the following year from the Recensement Général (Census, 2014), and the population growth rate of 3.6%.

$$Population\ RGPH + 1 = Population\ RGPH2014 * \ (1 + (Growth\ rate \div 100)$$

Ethical Consideration

This work has received ethical approval (N / Ref: 072 / MSHP / CNER-kp) from the National Ethics Committee of Côte d'Ivoire. The agreement of the Northwest and Central Ethics Committee of Switzerland was obtained (Ethics Committee of North Western and Central Switzerland (EKNZ) Basec-req 2016 00220). The project provided anti-rabies vaccine and immunoglobulin recommended by the WHO for the treatment of bites victims to the Ministry of Health and Public Hygiene.

Results

Results of the household survey

In households, 42% of bite victims sought help from health centres. Out of 8004 households, 116 dog bite victims were estimated. In rural areas, there were 65 victims, representing 56% of the victims recorded. In urban areas, 51 victims were registered, representing 44%

At the level of rabies management centres

The most recorded bite site is the foot with 64.1% of cases, followed by the arm with 25% and the area least affected by bites is the head or neck (Table 1).

Table 1: Proportion of bite sites in the departments of Bouaké and San Pedro between 2016 and 2017

Bites sites	Number	Percentage
Head or neck	104	3,1%
Arms	823	25%
Trunk	258	7,8%
Feet	211	64,1%
Total	3296	100%

In terms of age groups, those aged between 0 and 14 and those aged between 15 and 44 represent 55% and 32% respectively. The over 44 years represent 13% of bite victims (Figure I).

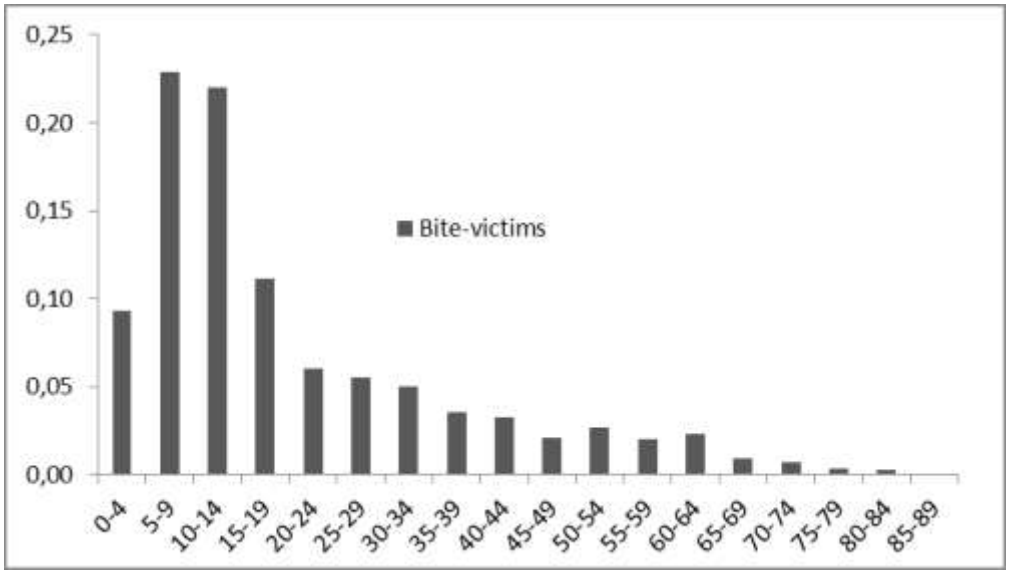

Figure I : Percentage of bite victims by age group between 2016 and 2017 in San Pedro and Bouaké

To the Veterinary Services of the study areas

Of the suspected rabies bites in the project sites, 83.3% of the suspected animals were confirmed by direct immunofluorescence testing. Dogs accounted for 70% of the positive suspects (Table 2).

Table 2: Number of positive suspect animals by species in Bouaké and San Pedro between 2016 and 2017

			TEST
Origin	**Species**	**Suspected cases**	**IFD**
Bouaké	Dog	7	5
	Cat	2	2

	Dog	2	2
	Cat		
San Pedro	Catle	1	1
Total		**12**	**10**

Estimation of human mortality due to rabies and DALYs lost

The incidence of rabies mortality in Côte d'Ivoire is estimated at 5.35 [95% CI 2.77-8.85] per 100’000 inhabitants from 2016 to 2017 with an annual incidence of 2.61 [95% CI1.81-3.5]. The

estimates of human rabies mortality in 2016 and 2017 are given in Table 3. We estimated that 1275 [95% CI 884-1698] humans died from rabies in Côte d'Ivoire with an annual number of deaths of 637 persons [95% CI 442-849]. DALYs lost, based on the current PEP coverage is estimated at 46'508 [95% CI 32'245-61'938] lost years from 2016 to 2017 in Côte d'Ivoire, with an annual DALYs lost estimated at 23'252 [95% CI 16'122-30'969]. If we consider lack of PEP, the DALYS would increase by 72.4% in 2017.

Financial cost

The total financial cost of rabies was obtained by combining the costs of premature death, seeking health care, PEP and prevention through vaccination of dogs. The financial costs due to canine rabies were 80.3 million USD [95% CI 55.6-106.9] in Côte d'Ivoire between 2017 et 2016, as shown in table 4. The annual cost of rabies was therefore 40.15 million USD [95% CI 27.8-53.4].

Overall, 99% of the cost of rabies was due to premature deaths. However, the assumption of 100% PEP reduces the cost of income loss due to premature death by 72,4%. The accessing PEP represented 1% of the financial cost of rabies and the costs related to the vaccination of dogs and the other expenses (transport and indirect cost) were less than 1% during the same period.

Table 3: Estimates of rabies mortality, incidence of rabies per 100,000 inhabitants with and without PEP, exposures, deaths prevented, average vaccination coverage, probability of a dog to be rabid (RA), and the probability to receive the PEP (PP) for 2016-2017

Region	**No. of deaths with current PEP coverage [95% CI]**	**No. of deaths without PEP [95%CI]**	**Human rabies incidence with PEP [95%CI]**	**Human rabies incidence without PEP [95%CI]**	**No. exposed to rabies suspected animal bites**	**Incidence of rabies suspected animal bites**	**Disability adjusted life years lost with current PEP coverage [95%CI]**	**Disability adjusted life years lost without PEP [95%CI]**	**RA**	**PP**	**1-PP**
Bouaké and San Pédro	70 [48-93]	121 [83-160]	5,35 [3.71-7.13]	9.23 [6.39-12.23]	1391	103	2’553 [1’750-3’392]	4’413 [3’027-5’836]	0,7333	0.42	0.58

Côte d'Ivoire	1275 [884-1698]	2198 [1522-2913]	5,35 [3.71-7.13]	9.23 [6.39-12.23]	24'630	103	46'508 [32'245-61'938]	80'184 [55'518-106'258]	0,7333	0.42	0.58

Table 4 : Financial cost of rabies in US dollars.

Region	**Cost of one dose of PEP**		**Cost of four doses of PEP (100%)**		**Cost of other expenses [95% CI] 2016 to 2017**	**Income losses due to premature death with current PEP coverage [95% CI] 2016 to 2017**	**Income losses due to premature death without PEP [95% CI] 2016 to 2017**
	2016	**2017**	**2016**	**2017**			
Bouaké et San Pédro	21'945	22'504	87'780	90'014	110'548 [-]	4'408'418 [3'022'915-5'856'898]	7'620'266 [5'227'124-10'076'385]

Côte d'Ivoire	398'466	408'838	1'593'865	1'635'350	20'4061 [-]	80'296'192 [55'672'027-106'935'635]	138'438'194 [95'851'612-183'453'184]

Discussion

The current study is the first estimate of the burden and financial cost of rabies in Côte d'Ivoire. The results will provide information needed for designing an adequate rabies control strategy. This information is fundamental towards achieving the goals set by the WHO and OIE for the elimination rabies by 2030. It also highlights the benefits that can be expected for the country if rabies could be eliminated. These benefits could even be higher if the cost of loss of livestock from exposure to rabies suspected dogs is included (Jibat et al. 2016). However, the losses linked to exposed livestock were not taken into account in our study. In fact, the World Organization of Animal Health (OIE) affirmed in 2011 that the reassessment of the global rabies situation (in humans and animals) and cost-effectiveness analyses of interventions should be finalized, in order to have up-to-date data to better promote the fight against rabies worldwide (OIE 2021).

The extrapolation of the results relating to the incidence of rabie from data collected in Bouaké and San Pedro, did not take cultural differences into account. It may be somewhat biased by the cultural difference between regions. Indeed, the northern regions are marked by the strong presence of Islam (Recensement Général 2014), which teachings discourage the keeping of dogs. The populations of these regions may have fewer dogs than those in the South and not be at the same risk of dog bites as the other regions of Côte d'Ivoire. Especially since one of the main bite risk factors in the household remains dog ownership (Kallo et al., 2020). This difference in the dog population between the different regions of a country, linked to religion, was observed by Léchenne et al. (2016) in Chad. The animal bite injury burden may thus not be equally distributed across the country, and further scoping studies are required to assess this on the ground.

The estimated incidence of 2.61 per 100’000 people per year in the study is much higher than that determined by Tiembré et al. (2010), whose data came from only human rabies care centers. He found an incidence of 0.028 per 100’000 inhabitants, a result 93 times lower than that which we found. A second study carried out by the same author in 2018, following the strengthening of the surveillance of human rabies, obtained from data collected between 2014 and 2016, an incidence of 0.08 (Tiembré et al. 2018). This result is 33 times lower than what we found. This big difference is explained by the fact that our estimates take into account the data collected in health centers, veterinary services and in households. Unlike the two studies previously carried out in Côte d'Ivoire, which only consider data from passive surveillance of health centers. This same observation was made by Cleaveland et al. (2002) who determined an incidence more than 100 times higher than that obtained from official data in Tanzania. Thus, multisectoral data collection improves case reporting. This highlights the added value of the collaborative multi-sectoral approach in rabies surveillance and shows the importance of a one health approach for rabies control. Indeed, Zinsstag (2015) defined the one health approach as the added value obtained in terms of human and animal health, resource savings and improvements in environmental impact, thanks to collaboration between human and veterinary medicine by comparison with maintaining a separation between these two disciplines.

Our estimate is similar to the annual incidence of 2.5 human rabies deaths/100 000 reported during active surveillance studies in Kenya’s Machakos District (Kitala,2000) but much lower than the incidence of human rabies predicted in Tanzania on the basis of active surveillance data on bite incidence (4.9 deaths/100000;Cleaveland, 2002). However, it is higher than that determined in Mali, with the same approach, which was estimated at 0.72 (Keita, 2020). This

difference could be due to the socio-cultural aspects that impact dog possession (Lechenne, 2016).

In addition, our study allowed us to determine the annual number of deaths in Côte d'Ivoire due to rabies which is 637 [95% CI 442-849]. This estimate is moderately higher thanthat determined by Hampson (2015), for Cote d'Ivoire, which was 569 deaths per year.

The calculated annual cost of rabies, which was US $ 40.15million [95% CI 27.8-53.4], is like the US $ 41 million estimated by Hampson (2) for the Côte d'Ivoire However in Mali the cost of rabies was estimated at 3.5 million USD [95% CI 2.1-4.6] in 2016 and 3.6 million USD [95% CI 2.4-4.5] in 2017(Keita, 2020). The financial cost of rabies is mainly due to the number years of premature lives lost, followed by costs associated with post-exposure prophylaxis. This observation was previously made by Hampson et al. (2015) and Keita et al. (2020). In our estimate we have not taken into account the financial loss related to anxiety and the cost to livestock (Jibat et al. 2016). Measuring the anxiety caused by bites during treatment is difficult, and Hampson's and Knobel's burden of rabies studies have not included it either (Hampson et al. 2015; Knobel et al. 2005). Hampson hypothesized that it could account for about 10% of total burden (Hampson et al. 2015).

The costs for the elimination of rabies by 2030 in Côte d'Ivoire are estimated at FCFA 19 billion (35 million USD). Our results show that it would be economically more profitable to eliminate rabies in Côte d'Ivoire by the mass vaccination of dogs since costs for elimination are much lower than the costs due to rabies calculated in this study. Indeed, the country's integrated rabies control program, which aims to eliminate rabies by 2030 at a cost of FCFA 19 billion (35 million USD) over twelve years (République de Côte d'Ivoire 2018) is equivalent to the annual

loss due to rabies in Côte d'Ivoire. Thus an investment of 19 billion (35 million USD) over 10 years in the fight against rabies will allow the Ivory Coast to save 10 times more resources.

Conclusion

This study highlights the underreporting of rabies cases and DALYs by the official health information system in Côte d'Ivoire, despite efforts to strengthen rabies surveillance. The annual financial losses related to rabies are equivalent to the estimated amount of the elimination of rabies by 2030.

Our estimation model can be applied in other countries where rabies reporting is problematic, particularly if there is a possibility to collect, even on a small, but representative scale with active surveillance data.

Conflicts of interest

The authors declare no conflict of interest

Authorship Statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Acta Tropica.

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