Incidence of human dog-mediated zoonoses and demographic characteristics/vaccination coverage of the domestic dog population in Algeria

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Summary

Control of zoonotic diseases requires a One Health integrated action from both human and animal health sectors. The aims of the present study were to estimate the incidence of dog-mediated zoonoses and to describe demographic characteristics and vaccination coverage of the domestic dog population in Algeria. The results show that rabies, leishmaniasis and echinococcosis are the major zoonoses in Algeria, with an average of 20.6 (deaths), 8,276 and 455 human cases per year, respectively. A door-to-door survey of 652 dog-owning households showed that 334 households (51.33%) were in urban areas and 318 (48.77%) in rural areas. The mean number of dogs per household in rural areas (2.02) is higher than that in urban areas (1.41). Furthermore, a high percentage of semi-confined and free-roaming and a low proportion of vaccinated dogs were recorded in rural areas. Vaccination coverage for rabies, canine distemper virus, Rubarth hepatitis, leptospirosis and parvovirus was lowest in rural dog populations. The analysis of risk factors established that semi-

confined or free-roaming dogs, non-pedigree breeds, hunting dogs, herding dogs and the presence of more than three dogs per household are risk factors for dogs not being vaccinated.

Keywords

Algeria – Demographic parameter – Dog – Human – Vaccination – Zoonosis.

Introduction

Dogs were domesticated by humans approximately 14,000 years ago and become associated very closely with human activities, including hunting, guarding and herding. This association was strengthened over time in many cultures, with dogs entering dwellings and sharing human space and time, and acting as social partners and companions (1). However, when dogs are not fully provided with food and shelter by humans, they will roam. Semi-confined and free-roaming dog populations can create risks for public health due to zoonotic diseases (2). It is known that more than 60 zoonotic diseases transmitted to humans are dog mediated, including those of significant concern such as rabies, leishmaniasis and echinococcosis (2, 3).

Zoonotic diseases are a major global threat to human and animal health; around 60% of all human diseases and around 75% of emerging infectious diseases are zoonotic (3, 4). Not only have emerging infectious diseases increased significantly over time, well-recognised infectious agents considered as neglected tropical diseases (NTDs) are also re-emerging – often in more virulent or drug-resistant forms (5, 6).

Zoonotic diseases are more complex in developing countries than in developed countries because of the lack of disease control and eradication programmes in these countries (7). The epidemiological situation is aggravated by underreporting, especially in Africa, Latin America and Asia. In these regions zoonotic NTD are estimated to kill around half a million people per year, and dog-mediated NTD such as rabies and leishmaniasis cause a significant portion of these mortalities (8, 9, 10). In Algeria, leishmaniasis and rabies are a public health problem because of the endemic nature of human cases and the economic burden of medical fees on the government budget (11, 12, 13). The epidemiology of these diseases is not well understood and not well documented.

Understanding the demography of domestic dog populations in the developing world is critical for planning effective population management and disease control (14), particularly for rabies, which causes around 59,000 human deaths per year (15), but also for other dog-mediated zoonoses prevalent in developing countries such as leishmaniasis and echinococcosis (2, 3). Demographic characteristics contribute to variations in population size, density, disease transmission and vaccination coverage (14, 15). The objectives of this study, therefore, were to estimate the incidence of dog-mediated zoonotic diseases in humans by using data from a 13-year national retrospective descriptive study and to describe demographic characteristics and vaccination coverage of the domestic dog population in Algeria.

Methods

Study area

Algeria is located between latitudes 19° and 37°N and longitudes 9°W and 12°E. It is bounded by the Mediterranean Sea to the north, Tunisia and Libya to the east, Morocco to the west, and Mali and Niger to the south. It has a long coastline at the Mediterranean Sea. Most of the coastal area (northern region) is hilly, and this is where more than 80% of the population lives. South of this region is a steppe landscape; farther south is the Sahara Desert (13). The Sahara region was excluded from the study, given the absence of dogs in this area.

Retrospective study of the incidence of dog-mediated zoonotic diseases in humans

The study design was a national descriptive retrospective study of dog-mediated zoonotic diseases in humans. The number of cases of rabies post-exposure prophylaxis (PEP) and deaths, the number of laboratory confirmed leishmaniasis cases (by indirect immunofluorescence) and the number of laboratory confirmed echinococcosis cases (by radiology/biopsy) from 1 January 2006 to 31 December 2018, were retrieved from the *Relevé épidémiologique annuelle*, an annual report published by the public health institute (INSP) at the Algerian Ministry of Public Health (16). Counting, data cleaning and analysis were performed using the Statistical Package for the Social Sciences (SPSS) software version 20.0 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, New York).

Demographic characteristics of the Algerian domestic dog population

A cross-sectional household survey with a two-stage clustering design, as described by Thrusfield (17), was carried out across the country between September and November 2014. The study covered rural and urban areas, as recommended by Downes *et al*. (18). Rural and urban households were selected in proportion to the population size in the relevant area. Forty-seven clusters were selected from a sampling frame of 1,327 municipalities. Fifteen households per cluster were sampled: the first household was chosen randomly and the subsequent ones were selected on the basis of their proximity to the first household. Data related to 203 stray dogs randomly sampled from animal shelters were also collected.

A tested questionnaire was administered to households by a door-to-door interview. The questionnaire contained information about demographic parameters such as age (puppy: less than 6 months; young: between 6 months and 30 months; adult: more than 30 months), sex, number of dogs per household, type of dog (pedigree/non-pedigree), dog function (hunting, herding, guarding, pet) and confinement status (confined, semi-confined, free-roaming). The chi-square test was used with 95% confidence levels in SPSS software version 20.0 to compare group differences for categorical variables.

Vaccination coverage of domestic dogs in Algeria

In Algeria, dogs are vaccinated against rabies, which is mandatory, with a single injection, and with other facultative vaccines (against canine distemper, Rubarth hepatitis, leptospirosis and parvovirus), which are combined in a single separate injection. Information about dog vaccination status was collected by a detailed examination of the vaccination certificates mandatorily delivered by veterinarians to the owners of each vaccinated dog (rabies, canine distemper virus, Rubarth hepatitis, leptospirosis and parvovirus). Dogs less than 366 days' post vaccination were considered vaccinated; dogs more than 366 days' post vaccination and dogs without a vaccination certificate were considered not vaccinated.

For the risk factor analysis, an initial exploratory analysis of the data (univariable) was performed using the chi-square test or Fisher's exact test. The variables that passed the cut-off ($p \leq 0.2$) were utilised for logistic regression (19). The fit of the final model was verified with the Hosmer and Lemeshow test, and collinearity between independent variables was verified by correlation analysis; for those variables with strong collinearity (correlation coefficient > 0.9), one of the two variables was excluded from the multivariable analysis according to the biological plausibility (20). Confounding was assessed by monitoring the changes in the model parameters when adding new variables. If substantial changes (i.e. $> 20\%$) were observed in the regression coefficients, this was considered as indicative of confounding. The calculations were performed using SPSS software version 20.0. The variables were considered as risk factors when the odds ratio (OR) was greater than 1.0 and the p value was less than or equal to 0.05.

Ethical statement

Dog owners participating in the study were informed about the purpose of the study and their verbal agreement was obtained. Veterinarians handled the dogs according to best practice. Ethical guidelines and animal welfare regulations were strictly respected.

Results

Retrospective study of the incidence of dog-mediated zoonotic diseases in humans

Rabies

In Algeria, rabies has been considered a major zoonosis and a priority since 1984 (13). Data from the Algerian Ministry of Public Health revealed that the number of human deaths caused by rabies ranges between 15 and 34 per year, with an annual average of 20.6 human rabies deaths (Table I). There was a significant recrudescence of PEP cases, from 67,583 in 2006 to 123,392 in 2018, with an average of 96,203 cases per year (Table I).

Table I

Evolution of annual incidence of post-exposure prophylaxis and human rabies death cases as recorded by the Public Health Institute (INSP) at the Algerian Ministry of Public Health

Year	PEP cases	Rabies death cases (male)
2006	67,583	31 (23)
2007	76,765	34 (25)
2008	74,321	22 (16)
2009	75,988	16 (13)
2010	97,321	19 (11)
2011	105,246	18 (15)
2012	109,811	17 (12)
2013	114,652	15 (11)
2014	118,456	19 (16)
2015	120,532	20 (17)
2016	120,952	18 (14)
2017	121,545	19 (16)
2018	123,392	20 (16)
Average	96,203	20.6 (16)

PEP: post-exposure prophylaxis

Leishmaniasis

Analysis of the data on leishmaniasis showed that, during recent decades, there was evidence of an increase in the *Leishmania* transmission rate in Algeria (Table II). The number of reported human cases ranged between 5,562 and 14,527, with an average of 8,276 human cases per year.

Cystic echinococcosis

The data show the enzootic trend of cystic echinococcosis (CE) incidence (Table II): the annual number of human cases ranges between 309 and 735, with an average of 455 cases per year.

Table II

Evolution of annual incidence of human leishmaniasis and echinococcosis as recorded by the Public Health Institute (INSP) at the Algerian Ministry of Public Health

Year	Leishmaniasis (visceral leishmaniasis)	Echinococcosis
2006	14,527 (93)	735
2007	6,635 (34)	661
2008	7,004 (38)	502
2009	6,468 (41)	450
2010	11,734 (84)	309
2011	10,843 (53)	352
2012	9,057 (48)	403
2013	6,437 (52)	415
2014	5,562 (30)	423
2015	7,523 (36)	474
2016	7,197 (41)	381
2017	7,368 (32)	398
2018	7,238 (35)	413
Average	8,276 (47)	455

Demographic characteristics of the Algerian domestic dog population

A total of 652 dog-owning households (DOHH) were interviewed during the study period (Table III), of which 334 (51.23%) were in urban areas and 318 (48.77%) in rural areas. The results showed a uniform distribution ($p = 0.371$) of dog-owning households across urban and rural communities. However, the number of dogs in rural areas (642 dogs; 57.58%) was significantly higher ($p = 0.028$) than that in urban areas (473 dogs; 42.42%). Furthermore, the mean number of dogs per household in rural areas (2.02) was higher than that in urban areas (1.41).

Table III

Differences in the number of households and the number of dogs per household between urban and rural areas

Number of dogs per household	Urban			Rural			*P*
	No. of households	No. of dogs	*P*	No. of households	No. of dogs	*P*	
1	271 (81.14%)	271	< 0.001	178 (55.97%)	178	< 0.001	0.028
2	39 (11.68%)	78		56 (17.62%)	112		
3	10 (2.99%)	30		34 (10.69%)	102		
> 3	14 (4.19%)	94		50 (15.72%)	250		
Total households	334	473		318	642		

Among the DOHH in urban areas, 271 households (81.14%) owned one dog, 39 (11.68%) two dogs, 10 (2.99%) three dogs and 14 (4.19%) owned between four and seven dogs. Among the DOHH in rural areas, 178 households (55.97%) owned one dog, 56 (17.62%) two dogs, 34 (10.69%) three dogs and 50 (15.72%) owned between four and twelve dogs.

The study revealed (Table IV) a statistically significant preponderance of male dogs ($p = 0.014$), with 77.37% in urban communities ($n = 366$), 61.68% in rural ($n = 396$) and 54.68% in the stray population ($n = 111$).

The overall median age of the dog population (Table IV) was 4.7 years (range 0.1–18) for males and 3.5 years (range 0.1–15) for females. A statistically significant predominance of adults ($p < 0.005$) was found when comparing age categories among urban, rural and stray dogs: older dogs represented 58.35% of urban ($n = 276$), 57.33% of rural ($n = 368$) and 56.66% of stray populations ($n = 115$).

Table IV

Demographic characteristics of the domestic dog population in Algeria

Variable	Categories	Urban		Rural		Stray		*P*
		No. (%)	*P*	No. (%)	*P*	No. (%)	*P*	
Age	Puppy	41 (8.67%)	0.011	58 (9.03%)	0.013	18 8.86%)	0.018	0.256
	Young	156 (32.98%)		216 (33.64%)		70 (34.48%)		
	Adult	276 (58.35%)		368 (57.33%)		115 (56.66%)		
Sex	Male	366 (77.37%)	< 0.001	396 (61.68%)	0.017	111 (54.68%)	0.028	0;0148
	Female	107 (22.63%)		246 (38.32%)		92 (45.32%)		
Type	Pedigree	415 (87.74%)	< 0.001	292 (45.48%)	0.065	0 (0%)	–	< 0.001
	Non-pedigree	58 (12.26%)		350 (54.52%)		203 (100%)		
Function	Hunting	32 (6.77%)	< 0.001	178 (27.73%)	< 0.001	–		< 0.001
	Herding	0 (0%)		230 (53.82%)				
	Guarding	314 (66.38%)		212 (33.02%)				
	Pet	127 (26.85%)		22 (3.43%)				
Confinement	Confined	308 (65.11%)	< 0.001	226 (35.20%)	0.067	–		< 0.001
	Semi-confined	165 (34.89%)		242 (37.69%)				
	Free-roaming	0 (0%)		174 (27.11%)				

Pedigree dogs predominated in urban areas (87.74%, $p < 0.001$), but in rural areas a uniform distribution was observed between pedigree (45.48%) and non-pedigree dogs ($p = 0.065$). All the stray dogs in the study were non-pedigree. Overall, the significantly most common ($p < 0.001$) function of dogs in urban areas was reported as guard duty (66.38%), followed by pet (26.85%) and hunting dogs (6.77%), and there were no herding dogs in these areas (Table IV). In contrast, the proportion of dogs used for herding (53.82%) was significantly higher ($p < 0.001$) in rural areas when compared with other duties. The proportion reported as guard dogs and pets (combined) was higher in urban than in rural areas ($p < 0.001$). Meanwhile, herding and hunting (combined) were the most commonly reported functions ($p < 0.001$) in rural areas (Table IV).

The movements of dogs living in urban areas were better controlled than in rural areas. Of the 473 dogs in urban areas, 308 (65.11%) were restricted at all times, 165 (34.89%) were allowed to roam for several hours per day, and none of the dogs was allowed to roam outdoors at all times (Table IV). In contrast, 27.11% (174/642) of dogs in rural areas were always allowed to roam outdoors and 37.69% (242/642) of dogs were semi-confined. The distribution of dogs by confinement categories was significantly different between urban and rural sites ($p < 0.001$). Furthermore, there was a marked difference ($p < 0.001$) in confinement practices reported by dog owners: fewer dogs were allowed to roam in urban areas, while there was no significant difference ($p = 0.067$) among the numbers of confined, semi-confined and free-roaming dogs in rural areas.

Vaccination coverage of domestic dogs in Algeria

The results revealed an overall rabies vaccination coverage rate of 68.78% (767/1115). Vaccination coverage was significantly higher ($p < 0.001$) in urban areas, with a rate of 81.40% (385/473), compared with rural areas, with a rate of 59.50% (382/642). In both dog populations (urban and rural), the vaccination coverage rate was similar in males/females and in adult/young dogs (Table V). However, the risk factor analysis for rabies vaccination coverage using the univariable analysis (Table V) followed by multivariable logistic regression (Table VI) confirmed that the presence of more than three dogs per household was a risk factor for not being vaccinated against rabies in urban (OR = 1.97) and rural (OR = 1.93) areas. In addition, our findings reveal non-pedigree (OR = 3.45) and semi-confined status (OR = 1.66) to be risk factors for not being vaccinated in urban areas. Non-pedigree (OR = 1.73), semi-confined (OR = 1.52), free-roaming (OR = 2.19), hunting (OR = 1.61) and herding dogs (OR = 1.82) were found to be at risk of not being vaccinated in rural areas.

Table V

Univariable analysis for risk factors associated with rabies vaccination coverage according to demographic characteristics in the Algerian domestic dog population

Variable	Categories	Urban			Rural		
		No. of dogs	No. of vaccinated dogs (%)	*P*	No. of dogs	No. of vaccinated dogs (%)	*P*
Age	Puppy	41	0 (0%)	0.483	58	0 (0%)	0.277
	Young	156	135 (86.53%)		216	136 (62.96%)	
	Adult	276	250 (90.58%)		368	246 (66.84%)	
Sex	Male	366	297 (81.14%)	0.761	396	250 (63.13%)	0.243
	Female	107	88 (82.24%)		246	132 (53.66%)	
Type	Pedigree	415	361 (86.98%)	< 0.001*	292	178 (60.96%)	0.042*
	Non-pedigree	58	24 (41.37%)		350	204 (58.28%)	
Function	Hunting	32	23 (71.87%)	0.048*	178	98 (55.05%)	0.041*
	Herding	0	0 (0%)		230	116 (50.43%)	
	Guarding	314	251 (79.93%)		212	150 (70.75%)	
	Pet	127	111 (87.40%)		22	18 (81.81%)	
Confinement	Confined	308	282 (91.55%)	< 0.001*	226	154 (68.14%)	0.067*
	Semi-confined	165	103 (62.42%)		242	148 (61.15%)	
	Free-roaming	0	0 (0%)		174	80 (45.97%)	
Number of dogs per household	1	271	261 (96.31%)	0.022*	178	126 (70.78%)	0.039*
	2	78	60 (76.92%)		112	70 (62.50%)	
	3	30	22 (73.33%)		102	62 (60.78%)	
	> 3	94	42 (44.68%)		250	124 (49.60%)	

* Variables selected and used in the multivariable analysis ($p \leq 0.2$)

Table VI

Risk factors (logistic regression analysis) for not being vaccinated against rabies, according to demographic characteristics of the Algerian domestic dog population

Variable	Risk factors	Urban					Rural				
		B	SE	OR	95% CI	*P*	B	SE	OR	95% CI	*P*
Type	Pedigree	Reference					Reference				
	Non-pedigree	0.874	0.418	3.45	2.14–5.36	0.002	0.698	0.461	1.73	1.25–2.54	0.038
Function	Pet	Reference					Reference				
	Hunting	–	–	–	–	–	0.714	0.456	1.61	1.38–2.56	0.035
	Herding	–	–	–	–	–	0.797	0.413	1.82	1.21–2.94	0.042
Confinement	Confined	Reference					Reference				
	Semi-confined	0.649	0.398	1.66	1.13–2.91	0.031	0.719	0.421	1.52	1.14–3.73	0.041
	Free-roaming	–	–	–	–	–	0.781	0.475	2.19	1.65–2.89	0.022
No. of dogs per household	1	Reference					Reference				
	> 3	0.807	0.423	1.97	1.21–2.88	0.025	0.777	0.409	1.93	1.38–2.36	0.028
		Hosmer and Lemeshow test: chi-square = 2.725; df = 6; *P* = 0.025					Hosmer and Lemeshow test: chi-square = 3.549; df = 7; *P* = 0.001				

df: degrees of freedom
B: beta coefficient
SE: standard error
OR: odds ratio
CI: confidence interval

The overall vaccination coverage rate for the other diseases (canine distemper virus, Rubarth hepatitis, leptospirosis and parvovirus) was 39.28% (438/1115). Vaccination coverage for these diseases was significantly higher ($p = 0.017$) in urban areas, with a rate of 48.20% (228/473), compared with rural areas, with a rate of 32.71% (210/642). Furthermore, the findings revealed (Table VII) that the vaccination coverage was similar in males/females and in adult/young dogs in both urban and rural areas.

The univariable risk factor analysis (Table VII) followed by multivariable logistic regression (Table VIII) confirmed that non-pedigree (OR = 2.18) and semi-confined dogs (OR = 1.95) and the presence of more than three dogs per household (OR = 1.21) were risk factors for not being vaccinated in urban areas. Non-pedigree (OR = 4.78), semi-confined (OR = 1.33), free-roaming (OR = 1.57), hunting (OR = 2.61) and herding dogs (OR = 3.07), and the presence of more than three dogs per household (OR = 1.45), were found to be risk factors for not being vaccinated in rural areas.

Table VII

Univariable analysis for risk factors associated with vaccination coverage for other vaccines, according to demographic characteristics, in the Algerian domestic dog population

		Urban			Rural		
Variable	Categories	No. of dogs	No. of vaccinated dogs (%)	*P*	No. of dogs	No. of vaccinated dogs (%)	*P*
Age	Puppy	41	0 (0%)	0.573	58	0 (0%)	0.696
	Young	156	83 (53.20%)		216	78 (36.11%)	
	Adult	276	145 (52.53%)		368	132 (35.86%)	
Sex	Male	366	179 (48.90%)	0.541	396	130 (32.82%)	0.735
	Female	107	49 (45.79%)		246	80 (32.52%)	
Type	Pedigree	415	206 (49.63%)	0.021*	292	152 (53.05%)	< 0.001*
	Non-pedigree	58	22 (37.91%)		350	58 (16.57%)	
Function	Hunting	32	10 (31.25%)	< 0.001*	178	48 (26.97%)	< 0.001*
	Herding	0	0 (0%)		230	50 (21.73%)	
	Guarding	314	133 (42.36%)		212	96 (45.28%)	
	Pet	127	85 (66.92%)		22	16 (72.72%)	
Confinement	Confined	308	173 (56.16%)	0.015*	226	82 (36.28%)	0.039*
	Semi-confined	165	55 (33.33%)		242	76 (31.40%)	
	Free-roaming	0	0 (0%)		174	52 (29.88%)	
Number of dogs per household	1	271	137 (48.75%)	0.018*	178	78 (43.82%)	0.019*
	2	78	42 (53.84%)		112	34 (30.35%)	
	3	30	14 (46.66%)		102	36 (35.29%)	
	> 3	94	35 (37.21%)		250	62 (24.80%)	

* Variables selected and used in the multivariable analysis ($p \leq 0.2$)

Table VIII

Risk factors (logistic regression analysis) of for not being vaccinated against diseases other than rabies, according to demographic characteristics in of the Algerian domestic dog population

Variable	Risk factors	Urban					Rural				
		B	SE	OR	95% CI	*P*	B	SE	OR	95% CI	*P*
Type	Pedigree	Reference					Reference				
	Non-pedigree	0.741	0.412	2.18	1.22–3.45	0.017	0.843	0.452	4.78	2.14–5.69	0.001
Function	Pet	Reference					Reference				
	Hunting	–	–	–	–	–	0.673	0.444	2.61	2.11–3.45	0.001
	Herding	–	–	–	–	–	0.799	0.473	3.07	2.15–5.02	0.001
Confinement	Confined	Reference					Reference				
	Semi-confined	0.611	0.405	1.95	1.16–3.25	0.028	0.731	0.387	1.33	1.15–2.58	0.043
	Free-roaming	–	–	–	–	–	0.685	0.391	1.57	1.11–2.78	0.039
No. of dogs per household	1	Reference					Reference				
	> 3	0.605	0.382	1.21	1.18–2.95	0.033	0.728	0.413	1.45	1.29–2.99	0.032
		Hosmer and Lemeshow test: chi-square = 2.529; df = 6; *P* = 0.031					Hosmer and Lemeshow test: chi-square = 3.725; df = 7; *P* = 0.011				

df: degrees of freedom
B: beta coefficient
SE: standard error
OR: odds ratio
CI: confidence interval

Discussion

Retrospective study of the incidence of dog-mediated zoonotic diseases in humans

The epidemiology of zoonotic diseases in Algeria is poorly documented. Data gathered from the Algerian Ministry of Public Health (16) suggest that rabies, leishmaniasis and echinococcosis are the major zoonoses in Algeria. It is worth mentioning that these diseases are underdiagnosed and underreported in Algeria owing mainly to the lack of facilities and means to perform laboratory diagnosis, especially in rural areas. This study analysed only the data reported by the Algerian Ministry of Public Health.

According to the Algerian Veterinary Services, the number of domestic carnivores vaccinated against rabies increased from 40,805 in 2011 to 79,342 in 2015. Furthermore, an average of 22,163 carnivores was culled per year between 2010 and 2015 (13). Despite these continued efforts, which have been implemented since 1996, the number of human and animal cases reported each year remains high: a reported average of 1,000 animal cases (13) and 96,203 PEP cases occur per year. The Algerian government covers the PEP treatment charges; therefore, the reported increase in PEP cases constitutes a huge burden for the governmental budget. It is obvious that a paradigm shift is required to tackle human rabies in Algeria, by focusing on immunisation of the primary reservoir hosts, domestic dogs, rather than concentrating on PEP as the only efficient means to prevent human deaths from rabies. Hampson *et al.* stated that there is a clear need for greater focus on dog vaccination as a more sustainable and cost-effective way of addressing rabies in humans (15). In addition, developing a better understanding of the demography and vaccination coverage of domestic dogs is highly recommended (18).

The notification of leishmaniasis became mandatory in Algeria in 1979 and the disease has been under surveillance since 1985. In 2006, a national leishmaniasis control and surveillance programme was created by the health authorities: the main actions undertaken are the recording of leishmaniasis cases, standardisation of treatment and vector control (11). Harrat *et al.* reported that leishmaniasis is a re-emerging disease in Algeria and seems to spread because of a combination of factors, including environmental changes, as well as factors related to the immune status of the host and drug resistance (11). Furthermore, Mihoubi *et al.* have stated that leishmaniasis represents 35% of the cases of notifiable disease in Algeria, leading it to rank first among the parasitic diseases in the country (12). Dogs are the main reservoir of the parasite and phlebotomine insects are the vectors (21). Adel *et al.* reported an estimated prevalence of leishmaniasis in dogs of between 11% and 38% in six localities along a west–east transect in the Algerian littoral zone (22).

Human visceral leishmaniasis (VL) caused by *Leishmania infantum* (MON-1) and *L. infantum* (MON-24), transmitted by *Phlebotomus perniciosus*, is the most severe form of leishmaniasis. It is almost entirely an infantile infection in Algeria (11). During the study period an average of 47 new cases was recorded per year. The incidence of human visceral leishmaniasis leading to death in the absence of treatment decreased from 0.94 per 100,000 inhabitants in 2001 to 0.49 in 2006 (12). However, human visceral leishmaniasis (VL) remains an important public health problem in Algeria.

Cutaneous leishmaniasis (CL) is manifested by two clinical forms in Algeria: *i)* zoonotic CL caused by *Leishmania major* (MON-25) and transmitted by *Phlebotomus papatasi*, and *ii)* sporadic CL of the North caused by *Leishmania infantum* (MON-24) and *L. major* (MON-80) and transmitted by *Phlebotomus perfiliewi* (21, 22). The burden of cutaneous leishmaniasis has rapidly increased during the last decade, with an enzootic mode: the number of cases ranges between 5,562 and 14,527 with an average of 8,276 cases declared per year. Cutaneous leishmaniasis, also called the Biskra boil, represents a real public health problem in Algeria, which is the second largest focus in the world after Afghanistan (12). The disease used to be mainly endemic in the steppe region until the last few years; a geographical extension towards the coastal regions has taken place (11).

Cystic echinococcosis is a widespread zoonosis caused by *Echinococcus granulosis*. The adult worm lives in the small intestine of carnivores (mostly dogs). The intermediate larval stage develops in the internal organs of many mammalian species (including humans), which acquire the infection through accidental ingestion of the tapeworm eggs (23, 24). Cystic echinococcosis is distributed worldwide but is most prevalent in Mediterranean countries; it is one of the major parasitic diseases in the Middle East and North Africa (25, 26). Both cystic and alveolar echinococcosis have been reported in these areas; however, cystic echinococcosis is the most frequent form (26, 27). Cystic echinococcosis remains highly endemic in North Africa and represents a serious public health problem, especially in rural communities where dogs live in close quarters with humans and domestic herbivores, feeding on scraps and offal from wild herbivores (28).

The persistence of the infection could be mainly explained by the feeding of stray dogs with offal discarded from animals slaughtered for human consumption that contribute to maintaining the life cycle of *Echinococcus granulosis*. In Algeria, CE is a serious economic and public health problem because of the huge medical fees associated with surgical treatment and the loss of livestock. The common sheep/dog cycle continues to be the major source of human contamination (28).

The occurrence of these three zoonotic diseases is favoured by the presence and uncontrolled proliferation of household waste deposits coupled with semi-confined and free-roaming dogs. Therefore, prevention and control of these diseases can only be successful through inter-sectoral collaboration and continuous interventions focused on animal, human and environmental aspects. Such collaboration among the departments of health, Veterinary Services and the environmental agency is important for the control of zoonoses in Algeria and thereby the elimination of transmission to humans (29).

Demographic characteristics of the Algerian domestic dog population

The demographic characteristics of host populations have a profound impact on the transmission and maintenance of pathogenic agents; therefore, understanding the demography of targeted populations will be key to the success of future surveillance and control programmes (30). Such knowledge can influence logistical decisions such as the quantity of vaccines required and the frequency of vaccination campaigns (6, 31). This is the first contribution to characterise the demography of the domestic dog population in Algeria, and in North Africa, and was designed to investigate their ecology and distribution across urban and rural communities.

Cross-sectional household surveys have been recommended for studying the population demography of owned dogs and their vaccination coverage (18). Through such surveys, the proportion of households that own dogs and the mean number of dogs owned by these households can be determined (2, 18). For instance, the proportion of households that own dogs has been studied in numerous countries using cross-sectional household surveys, including Chile (rural 89%, towns 63% and cities 49%) (30), Zimbabwe (rural 62%) (31, 32, 33) and Mexico (urban 54%) (34).

The results of the door-to-door survey in this study demonstrated that most (81.14%) householders in urban areas had only one dog. In rural areas, almost half (44.03%) of householders had two dogs or more. Therefore, the study found significant differences in the number of dogs per DOHH between urban and rural communities. Several studies have reported the same observations in different countries, such as Zimbabwe (31, 32, 33), Mexico (34), Kenya (35), Ethiopia (36) and Indonesia (37).

The results found in this study indicate that the sex ratio is skewed towards males, which is consistent with findings from other parts of the world (31, 32, 33, 34, 35, 36, 37), but is more marked in this study than elsewhere.

Although dogs were confined in a higher proportion of urban households than rural households, one of the important findings that could have consequences for pathogen transmission and maintenance in the study area is the significantly higher density of dogs in rural areas. The high density of dogs in these areas, coupled with the free-roaming behaviour of many of these dogs, provides ideal conditions for the persistence of pathogenic infections (35, 36, 37). This finding is typical of many developing countries, where the majority of dogs are only temporarily restricted in their activities and movements, if at all. For example, it was reported that 69% of owned dogs were never restricted and ranged freely in the Machakos district of Kenya (35), and 89.5% of owned dogs were always free to range in Zimbabwean communal lands (32, 33).

Vaccination coverage of domestic dogs in Algeria

Dog vaccination is a valuable component for building high herd immunity with the aim of preventing the spread of rabies and other dog-mediated zoonotic diseases, and when deployed effectively can eliminate infections (14). Among the most critical factors that determine the effectiveness of vaccination is the level of vaccination coverage achieved: vaccination of at least 70% of the dog population is considered necessary to eliminate rabies infection (38). However, population turnover poses a challenge to maintaining sufficient levels of vaccination coverage (39). Declines in vaccination coverage occur as vaccinated animals die and susceptible puppies are born, or new unvaccinated animals are brought into the population. Therefore, in the aftermath of a vaccination campaign, coverage can rapidly decline; even relatively small gaps in vaccination coverage can facilitate the persistence of infections (40, 41).

The findings of this study revealed an overall rabies vaccination coverage rate of 68.85% (767/1115). A similar figure was reported in Tunisia by Touihri *et al.*, where 70% vaccination coverage was found (42); however, Darkaoui *et al.* stated that the vaccination coverage in Morocco from 2009 to 2015 never exceeded 6% of the total dog population (43). In Algeria, vaccination coverage was significantly higher in urban areas, with a rate of 81.40% (385/473), than in rural areas, with a rate of 59.50 (382/642). Townsend *et al.* reported that the dog population in developing countries generally receives little veterinary care, and dogs in rural areas are even less likely to receive veterinary care than those in urban areas; these dogs also tend to be plagued by disease and parasitism and are less likely to be vaccinated (40). The same observation was recorded in Tunisia (42) and Morocco (43).

The vaccination coverage rate for canine distemper virus, Rubarth hepatitis, leptospirosis and parvovirus was 39.28% (438/1115). Dogs are often considered a primary reservoir of these diseases and a source of infection for wild species. Acosta-Jamett *et al.* reported that mass vaccination of dogs has been successful in controlling the incidence of these diseases and preventing their transmission in Chile (44). The vaccination of dogs has been incorporated in Algeria's management programmes since 1996, but its effectiveness in controlling these diseases in dog populations remains to be fully evaluated (45).

Vaccination coverage for rabies, canine distemper virus, Rubarth hepatitis, leptospirosis and parvovirus was lower in rural dog populations. The analysis of risk factors established that semi-confined or free-roaming, non-pedigree, hunting and herding dogs, and the presence of more than three dogs per household, are risk factors for not being vaccinated. These findings are typical of many developing countries, where non-pedigree and rural dogs receive less attention from their owners and are likely to remain unvaccinated (38). Furthermore, the presence of more than three dogs per household amplified the risk of not being vaccinated in both urban and rural areas. The high density of dogs within these households was due to the presence of newly born puppies, and the low vaccination coverage in this category was also likely due to insufficient targeting of puppies. It is a common perception that puppies cannot be vaccinated because they are too young; however, Yahiaoui *et al.* reported that even extremely young dogs in endemic regions such as Algeria have been shown to respond very well to rabies vaccination (45).

Conclusions

This study revealed that rabies, leishmaniasis and cystic echinococcosis remain present in humans in Algeria and are most likely underreported; dogs are reservoirs for these diseases and dog vaccination coverage is non-optimal, especially in rural areas. This study also demonstrated substantial differences in the demographic characteristics of dog populations in urban and rural areas in Algeria, which are likely to have important implications in disease transmission in an urban/rural complex. The demographic characteristics show broad similarities to those of populations in comparable settings in other parts of the world, and suggest consistent patterns of dog ownership, confinement and management in a wide range of countries. The size and density of dog populations were particularly high in rural areas, with a high percentage of semi-confined and free-roaming, and a low proportion of vaccinated, dogs. These areas provide ideal conditions for the maintenance of a high and dense population of susceptible hosts that have the potential to act as reservoirs of directly transmitted canine and zoonotic pathogens.

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