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Antimicrobial resistance risks associated with wild boar consumption and handling: knowledge, attitudes and practices in selected Italian regions

Claire Julie Akwongo[1,2,3], Maria Francesca Peruzy[1]✉, Kurt Houf[2], Luca Borrelli[1,3], Alessandro Fioretti[1] & Nicoletta Murru[1,3]

Antimicrobial resistant (AMR) organisms can be transmitted to humans by wildlife including wild boars through environmental contamination or through the food chain. Understanding the risks associated with handling and consuming wild boar meat is crucial for ensuring consumer safety. This study assessed knowledge on wild boar associated AMR risks, attitudes towards AMR risk mitigation efforts and supporting practices (KAP) among participants from eight regions of Italy. Data was collected using a standardized online questionnaire. Responses were weighted using the Likert scale and categorized according to Bloom's cut off points. Associations between KAP scores and determinants were assessed using linear regression analyses and Kendall's tau rank correlation. A total of 97 responses were received from 53 adult female and 44 adult males, among whom were 66 (68%) consumers and 31 (32%) non consumers of wild boar meat. The mean knowledge score was 27.8%, mean attitude score was 42.7% and mean practices score was 77.4%. There was a positive correlation between knowledge and attitude scores ($\tau = 0.52$, $P < 0.05$), but not with practices ($\tau < 0.3$, $P > 0.05$). Regression analyses revealed that the levels of knowledge, attitudes and practices varied significantly ($P < 0.001$) between genders, age groups and sector of occupation but not education levels ($P > 0.05$). The findings reveal a need for reinforcement and enrichment of the existing AMR awareness creation tools to include information on AMR and food safety risks from wildlife.

Keywords Public health, Food safety, Antibiotic resistance, Wild boar

Antimicrobial resistance (AMR) has emerged as one of the most pressing challenges to global health, undermining decades of progress in treatment and control of infectious diseases[1]. The rapid evolution and dissemination of resistant microorganisms not only compromises the efficacy of therapeutic agents but also poses risks to food safety and animal health[2]. The AMR situation in Italy is quite alarming. It has been ranked as the country with the highest number of deaths related to antimicrobial resistance in the European Union[3,4].

Resistant microorganisms can be transmitted to humans through various routes, including environmental exposure and the consumption of contaminated food products[5]. The evolution of AMR has been accelerated by the misuse and overuse of antimicrobials in human and veterinary medicine, as well as in agriculture[2]. Moreover, environmental contamination by medical, industrial, and agricultural wastes has been implicated in the dissemination of AMR in the natural environment[6]. Relatedly, studies have shown that even wildlife, which are not directly exposed to antimicrobials, can acquire resistant bacteria from their environment[7,8]. Wild boars (*Sus scrofa*) are of particular interest as potential reservoirs of AMR bacteria due to their omnivorous feeding habits and the increasing overlap between their habitats and the human and livestock-dominated landscapes[9].

In Italy, wild boar meat has long been appreciated for its distinctive flavor and nutritional profile, with regional culinary traditions often including it in stews, roasts, and cured products[10,11]. Moreover, the availability of wild

[1]Department of Veterinary Medicine and Animal Production, University of Naples Federico II, Via Federico Delpino 1, Naples 80137, Italy. [2]Department of Veterinary and Biosciences, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, Merelbeke 9820, Belgium. [3]Task Force on Microbiome Studies, University of Naples Federico II, Naples, Italy. ✉email: mariafrancesca.peruzy@unina.it

boar meat in Italy has increased more than ever in the last decades as government programs to control wild boar populations have encouraged hunting activities[12,13]. The heightened human interaction with wild boars through hunting as well as consumption of their meat may be an avenue to increased risk of transmission of drug-resistant microorganisms to humans. However, it is important to note that the mere presence of resistant bacteria in meat does not by itself translate into its transmission to humans, but the risk is determined by many factors including the subsequent handling, processing, storage and cooking practices[14]. In many artisanal and small-scale operations where standard hygiene protocols may not be strictly enforced, there is an increased risk that cross-contamination may occur[15]. This underscores the importance of proper food safety management systems throughout the production and supply chain. Given the multifaceted risks associated with AMR transmission through meat, an essential component in mitigating these risks lies in correct knowledge, attitudes and practices (KAP) of both handlers and consumers[16]. This is particularly important given that wild boar meat often escapes the inspection applied in conventional meat production and may follow a less standardized processing chain[15].

The present survey is aimed at assessing the level of awareness of wild boar meat consumers and handlers on the public health threat of AMR and its potential for transmission through consumption of wild boar meat, exploring attitudes towards consumption of wild boar meat in relation to its perceived safety, quality and association with AMR, as well as identifying current practices that may influence the risk of AMR transmission.

Methods

Study location

A cross-sectional study was conducted over a 6 months period between September 2024 and February 2025, coinciding with the wild boar hunting season in Italy. Italy's heterogenous landscape with mountains, extensive forested areas and intensive agricultural plains support a dense wild boar (*Sus scrofa*) population that is considered the most widespread ungulate in the country and a potential reservoir of antimicrobial resistant bacteria[17]. The wild boars are abundant across all the macro-regions, frequently interacting with livestock, crops and human settlements, especially in peri-urban zones where they exploit anthropogenic food sources[18]. Although the questionnaire was distributed nationwide, completed surveys were obtained from eight administrative regions: Campania, Umbria, Lazio, Liguria, Veneto, Sicilia, Piemonte and Lombardia (Fig. 1). These regions represent a broad longitudinal gradient from the northern Alps to the southern islands, and encompass diverse hunting traditions, meat handling practices and levels of wildlife-livestock-human interface. Consequently, the sample set captures variation in exposure risk associated with wild boar consumption and handling throughout Italy, while acknowledging the fact that data from the remaining regions were not available for analysis.

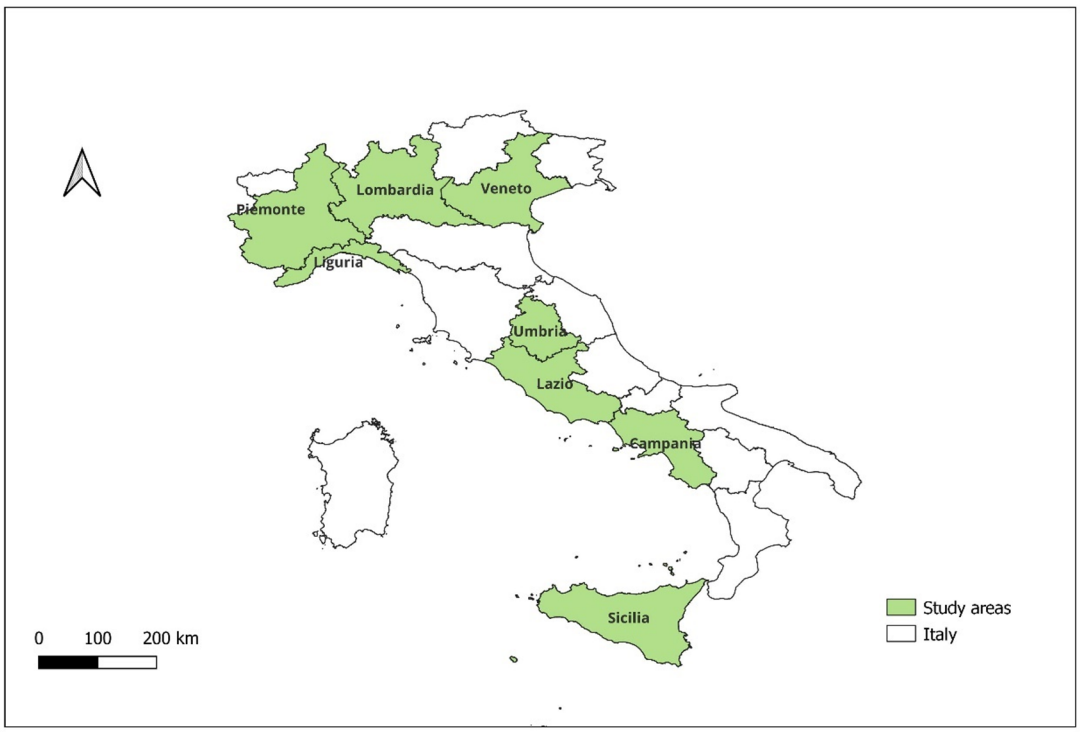

Fig. 1. Map of Italy showing the eight study regions. The map was generated by the authors in QGIS desktop version 3.28.15 (https://qgis.org/project/) using shapefiles downloaded from https://public.opendatasoft.com/explore/assets/georef-italy-regione/export/.

Sampling strategy

The sampling strategy was a simple random sampling and the sample size was calculated using Cochran's formula for large or unknown populations[19,20]

$$n = \frac{z^2 pq}{d^2}$$

Where z = 1.96 at 5% level of significance, d = the acceptable margin of error set at 0.07, p = 10% q = 90%. Since there was no data from previous studies in Italy, the sample proportions p and q were randomly set at 10% and 90% respectively. Eventually, the minimum required sample size was set at 70, and a random sampling approach was applied to select participants for recruitment in the study.

Data collection

The key data collection tool used for this study was a semi-structured questionnaire (Supplementary material 1) designed in Italian by the research team, through a multistage process to ensure content validity, reliability and contextual appropriateness. First, the study objectives were defined as (1) to assess the extent to which consumers and handlers of wild boars in Italy understood the phenomena of AMR and its transmission pathway through the wild boar meat chain (2) assess the perceptions of risk, confidence in control measures and willingness to adopt preventive and control practices, (3) assess hygiene behaviors, handling and cooking methods as well as adherence to safe meat preparation procedures. Following this, a review of published studies and documents on AMR, zoonotic pathogens and food borne disease transmission risks from key organizations including the centers for disease control (CDC), World Health Organisation (WHO), World Organisation for Animal Health (WOAH) and the European Food Safety Authority (EFSA) was done to inform the conceptual framework, which was then used to generate a draft questionnaire. A panel of four experts in epidemiology, veterinary microbiology and food safety reviewed the draft questionnaire for scientific accuracy, relevance and clarity and their feedback was used to refine and draft the data collection tool. The tool was validated with five respondents representative of the study population to ensure clarity of the questions as well as cultural appropriateness. Consequently, it was adjusted based on the ease with which the pre-test respondents understood the questions, and their general flow and correctness. Finally, a pre-test was done in two rounds with another set of five participants to evaluate consistency and flow. Reliability of the tool was assessed by calculating the Cronbach's alpha for Likert scale items[21]. Items with a coefficient ≥ 0.7 were noted as having acceptable reliability and were maintained in the questionnaire while those ≤ 0.7 were revised or excluded from the questionnaire. The final survey tool consisted of four main sections including (1) demographic information of the participants, (2) wild boar meat consumption and handling practices, (3) knowledge on AMR, (4) attitudes towards AMR risk mitigation and was uploaded online as a google form. Inclusion criteria required participants to be resident in any part of Italy and be at least 18 years old. The link to the google form was shared with participants through different social media platforms including LinkedIn, Facebook, WhatsApp groups and email groups. Some participants were recruited during public events across Italy, where they accessed the same link using their own devices. After reading the research description, the information on informed consent, and the right to withdraw from the study, the participants voluntarily made the decision on whether to participate or not at their own convenience. Completed questionnaires were immediately received by the research team via Google Sheets.

Data analysis

A summary of all responses was automatically transferred from the Google sheets to a Microsoft excel sheet, which was downloaded at the end of the survey period. All responses were examined for consistency and completeness before transformation into a form suitable for analysis. Knowledge, attitudes, and practices were rated using the Likert scale[22], and categorized according to Bloom's cut off points[23] as applied by other KAP studies[24,25].

Total scores for each participant were obtained by adding the scores from all questions for each parameter. The total score was then divided by the maximum possible score for each parameter and multiplied by 100 to obtain a percentage. They were then assigned to a category based on the percentage obtained. Knowledge levels less than 60% were categorized as low, 60–79% as moderate, and 80–100% as high. Similarly, attitudes were considered negative if scores were less than 60%, neutral if 60–79%, and positive if 80–100%. Practices were categorized as bad/inadequate if total scores were below 60% and good/adequate if 60% and above.

Descriptive statistics including frequencies, means and averages were used to summarize the data, while univariate and multivariable linear regression analyses were performed to determine associations between variables. Model assumptions for the multivariable regression models were evaluated using both graphical and formal diagnostic procedures; linearity was assessed using residuals vs. fitted plots, while normality of residues was examined using Q-Q plots and the Shapiro-Wilk test. Homoscedasticity was evaluated using the residual plots and the studentized Breusch-Pagan test (Supplementary material 2). Kendall's tau rank correlation was used to assess the strength of association between knowledge and attitudes, knowledge and practices, and attitudes and practices. The correlation was considered weak if the τ value obtained was 0 ± 0.3, moderate if 0.3 ± 0.5, strong if 0.5 ± 0.7 and very strong if 0.7 ± 1. Classification as positive or negative correlation was determined based on whether the τ value was positive or negative[26]. Analyses were performed in the CRAN project's R software version 4.5.1 (https://cran.r-project.org/), with p-values of ≤ 0.05 considered significant. Additional graphs were generated in Microsoft Excel version 2510.

Ethical considerations

The survey protocol was approved by the research ethics committee of the University of Naples Federico II (PG/0025382). All methods were performed in accordance with the world medical association declaration of Helsinki for studies involving human participants. Informed consent was obtained from the respondents prior to recruitment for the study as indicated in supplementary material 1, in that after reading the informed consent statement describing the purpose of the study, voluntary participation, confidentiality and the right to withdraw at any time before submission, the participants were required to indicate their consent by selecting " Yes, I have read and understood the information above and voluntarily agree to participate," in a mandatory multiple-choice question. Conditional logic was applied such that only participants who provided consent were allowed to proceed to the rest of the questionnaire. Participants who selected "No, I do not agree or consent to participate in the study" were automatically directed to an exit page and the form was terminated without access to the study questions. No data was therefore collected from participants who did not provide consent. For the consenting participants, no personal information including names, phone numbers, email addresses, home or work addresses was collected, ensuring anonymity.

Results

General characteristics of respondents

Responses to the survey tool were obtained from 97 participants, 53 of whom were female and 44 male. The responses were received from 8 regions that geographically belonged to the northern, southern and central parts of Italy (Table 1).

Variables	Category	Number	Percentage
Sex	Female	53	54.6
	Male	44	45.4
Age (Years)	18–25	18	18.6
	26–35	27	27.8
	36–45	19	19.6
	46–50	2	2.1
	> 50	31	31.9
Highest level of Education	Elementary school certificate	1	1
	Lower secondary school certificate	3	3.1
	High school Diploma	24	24.7
	Undergraduate	59	60.9
	Postgraduate	10	10.3
Sector of occupation	Government	13	13.4
	Health	16	16.5
	Sciences (other than health)	5	5.2
	Academia	6	6.2
	Student	24	24.7
	Private	19	19.6
	Retired	6	6.2
	Unemployed	8	8.2
Region	Campania	79	81.4
	Umbria	1	1
	Lazio	6	6.2
	Liguria	1	1
	Veneto	2	2.1
	Sicilia	1	1
	Piemonte	5	5.2
	Lombardia	2	2.1
Geographical location	Northern	10	10.3
	Southern	80	82.5
	Central	7	7.2
Hunting tendency	Hunter	4	4.1
	Non hunter	93	95.9
Consumption tendency	Consumer	66	68
	Non consumer	31	32

Table 1. General characteristics of study participants.

Generally, consumption of wild boar meat was high among the participants (68%), the practice being more common among male (81.8%; 36 of 44) than female (56.6%; 30 of 53) respondents. Moreover, among those who did not consume wild boar meat, 2 indicated that they acquired wild boar meat for other people including family members and friends. Majority of the respondents acquired wild boar meat from meat shops (37.8%) or directly from hunters (32.4%). Other sources of wild boar meat included supermarkets, restaurants, grocery shops and gifts from other people (Fig. 2).

The wild boar meat was mainly acquired in fresh form (46.2%), as frozen meat (23.1%) or as cold cuts (*Salumi*) (21.8%). A few participants obtained it as smoked meat (3.8%) and already cooked, especially in restaurants (3.8%). The meat also came in the form of ingredients of other food products sold in supermarkets (1.3%) (Fig. 2).

More than half of the study participants (51.3%) consumed wild boar meat "in ragù", a form of sauce often served with pasta. Additionally, 17.5% and 15% of the participants consumed it as cured meat (*in Salumi*) and stews, respectively (Fig. 2). An equal number (7.5%) preferred it roasted and/or pan-fried, while a minority consumed it baked (1.2%). While 49.5% of participants indicated that they conserved leftover wild boar meat for future consumption, more than half (50.5%) did not. They either consumed all that was prepared or discarded the leftovers. Half of those who conserved wild boar meat kept it in the fridge, while 28% and 22% kept it in the freezer and vacuum freezer, respectively.

Sources of information on AMR

Most of the informants (75 participants; 77.3%) indicated that they had received information on AMR. Of these, 56 (74.7%) had received information about the possible risk of spread of resistant bacteria via consumption of contaminated wild boar meat, while 19 (25.3%) had not. Information regarding antimicrobial resistance was accessed through single (79.2%, $n=72$) or multiple channels (20.8%, $n=72$), most frequently through social media platforms (36%, $n=100$) and formal education establishments (28%, $n=100$) as illustrated in Fig. 3. The information was mostly relayed to the public by veterinarians (65.3%, $n=72$) and medical personnel (20.8%, $n=72$). Other professionals like biologists (8.3%, $n=72$) also played a role in the dissemination of information on AMR, though not so commonly. Moreover, some respondents also reported receiving information from individuals without specific qualifications (5.6%, $n=72$).

Scores of Knowledge, attitudes and practices

From the assessment, the mean score of knowledge on AMR in relation to wild boar meat handling and consumption was 27.8%, while mean scores for attitudes and practices were 42.7% and 77.4% respectively. As shown in Figs. 4 and 85.6% of the participants were categorized as having low knowledge, while 7.2% exhibited high levels of knowledge and 7.2% moderate levels. Attitude scoring showed that 59.8% held a negative attitude, 28.9% were neutral, while 11.3% carried a positive attitude towards AMR control measures. Conversely, 94.8% of the respondents exhibited good (adequate) practices, and 5.2% bad (inadequate) practices as regards behaviors related to AMR risk mitigation.

Knowledge of AMR in relation to wild boars

As shown in Table 20.6% of the participants reported having received some form of training on safe handling of wild boar meat, with much of the trainings being conducted recently. Regarding AMR, at least 77.3% were aware of the phenomenon, but only 74.3% provided a correct description and explanation of it. Despite the high level of awareness on the existence of AMR, more than half of the participants were unaware or not sure of the possibility of spread of AMR through contact with or consumption of wild boars. Moreover, only 19.6% stated correct reasons why they thought there was an AMR transmission risk associated with wild boars.

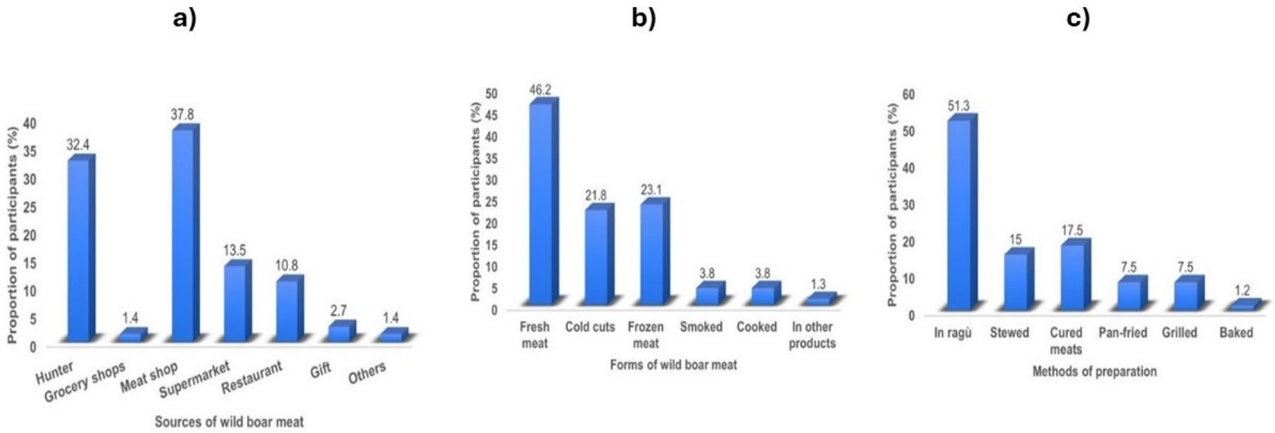

Fig. 2. **a**) Sources of wild boar meat ($n=74$), **b**) forms in which it is acquired by consumers ($n=78$), and **c**) the preferred methods of its preparation ($n=80$) as reported by survey participants from 8 regions of Italy. The denominators were the count of all responses, including multiple responses from individual participants.

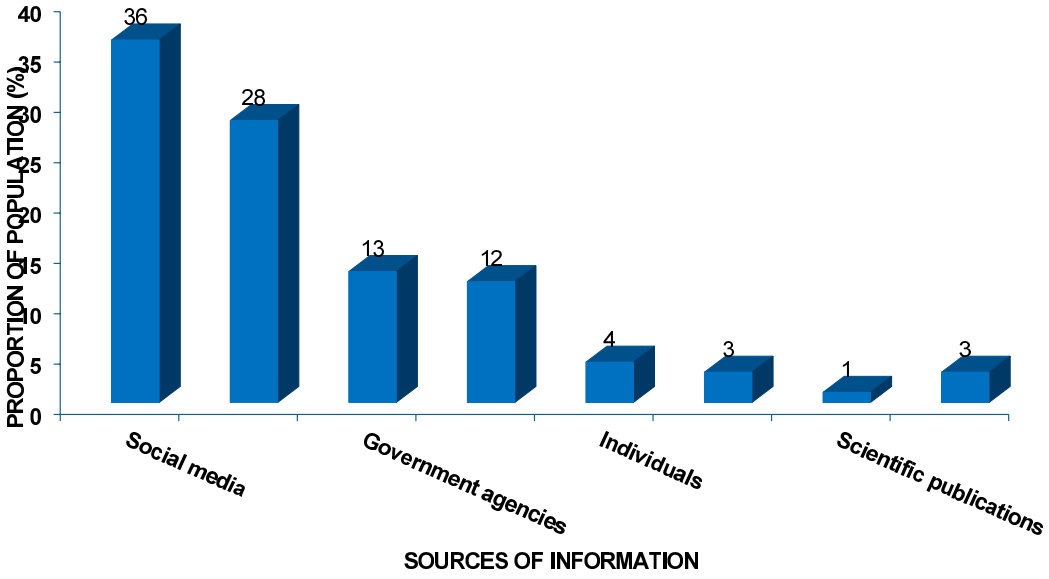

Fig. 3. Platforms on which information on antimicrobial resistance is accessed by study participants ($n = 100$). The denominator was the count of responses received for all sources of information including from participants who indicated multiple sources.

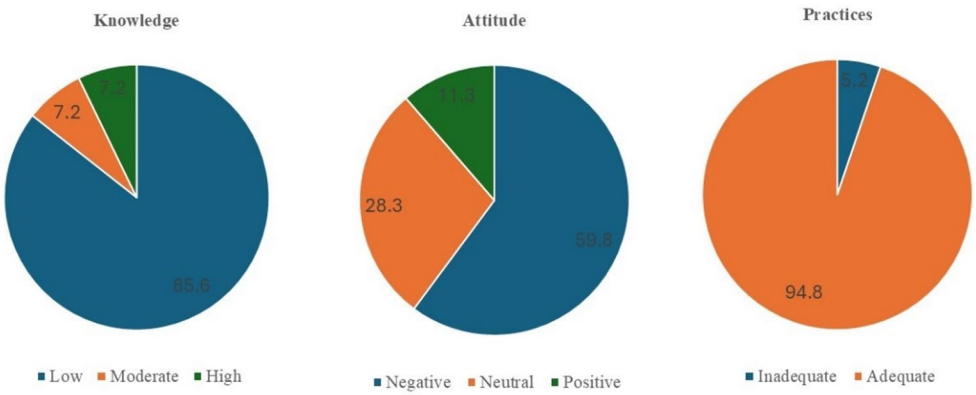

Fig. 4. General scores of knowledge, attitude and practices related to the risk of transmission of AMR from wild boar meat. The assessment was done for 97 participants from 8 regions of Italy.

Of the 19 participants who provided correct responses, representing 19.6% of all respondents (Table 2), 12 (63.16%) associated AMR risk from wildlife with the fact that they are frequently in contact with the human and livestock populations both in urban and wild environments and may pick up resistant bacteria from the environment due to their habit of rummaging through wastes. Additionally, the lack of sanitary controls for wild boar meat and the potential for humans to contract other infections from wild meat were highlighted by 3 participants (15.79%). Moreover, mention was made of the way wild boar meat is handled by hunters and untrained personnel, and sometimes without the use of personal protective equipment (PPE), which could lead to contamination of the wild boar meat with resistant organisms and subsequent transmission to consumers by 3 participants (15.79%). One respondent (5.26%) also acknowledged the fact that some resistant organisms may naturally be present in the environment and therefore can be picked up by wild boars from the soil, water or even other wild animals in the same habitats.

Of the 78 participants who did not provide correct reasons why they thought/did not think there was an AMR transmission risk associated with wild boars, 69 (88.5%) simply did not see the relationship between consumption of wild boars and the risk of AMR transmission to consumers. Three key misconceptions about AMR in relation to wild boars were identified among the remaining 9 respondents (11.5% of the 78). Six of the 9 (66.7%) believed that since wild boars live in the wild and are not treated with antibiotics like livestock, it is not possible for them to carry resistant organisms. Also, there was a notion that because they are free-living animals,

Questions	Response	Number	%
Have you ever received training on safe handling of wild boar meat	Yes	20	20.6
	No	77	79.4
When was the last time you received training on handling wild boar meat?	Never	77	79.4
	A few months ago	4	4.1
	1 year ago	9	9.3
	2 years ago	5	5.1
	3 years ago	0	0
	4 years ago	0	0
	5 years ago	0	0
	More than 5 years ago	2	2.1
Have you ever heard of the term antimicrobial resistance?	Yes	75	77.3
	No	22	22.7
Describe antimicrobial resistance	Correct description	72	74.2
	Wrong /No description	25	25.8
Do you believe that antibiotic resistant organisms can be spread to humans through consumption of wild boar meat?	Yes	47	48.5
	Unsure	19	19.6
	No	31	31.9
Provide reasons why you think AMR may or may not be transmitted through consumption of wild boar meat.	Correct reasons	19	19.6
	Wrong reasons	78	80.4
What measures do you use to prevent AMR transmission through wild boar meat?	Correct measures	22	22.7
	Wrong/no measures	75	77.3

Table 2. Status of knowledge of 97 survey participants from 8 Italian regions regarding AMR risks from handling and consumption of wild boars.

Questions	Response	Number	%
How concerned are you about the possibility of transmission of AMR through consumption of wild boar meat?	Not concerned	33	34
	Moderately concerned	52	53.6
	Very concerned	12	12.4
Would you be willing to participate in screening tests as part of AMR surveillance programs?	Yes	57	58.7
	Undecided	12	12.4
	No	28	28.9
Do you think there is need for better regulations on AMR control?	Yes	77	79.4
	No	20	20.6
Provide suggestions on better ways to control AMR spread.	Provided	27	27.8
	Not provided	70	72.2

Table 3. Status of attitudes of 97 survey participants from 8 Italian regions towards AMR control.

they are safe (1 participant, 11.1%). Moreover, two participants (22.2%) also reasoned that since wild boar meat is less manipulated than other types of meat, it poses no AMR risks.

A total of 22 participants (22.7%) correctly stated measures for prevention of transmission of resistant bacteria from wild boar meat to humans, 15 of whom mentioned single measures while 7 multiple. These included the use of PPE like gloves while handling meat (10; 31.25%, $n = 32$),, washing hands after handling wild boar meat (7; 21.875%, $n = 32$), ensuring that meat is well-cooked before eating (7; 21.875%, $n = 32$), disinfecting surfaces and utensils where meat is prepared (4; 12.5%, $n = 32$), conserving meat at correct temperatures (2; 6.25%, $n = 32$), and buying the meat from regulated sources (2; 26.25%, $n = 32$).

Attitudes towards AMR risk mitigation

There were differing views towards the risk of AMR transmission to humans from wild boar meat. As summarized in Table 3, more than half of the respondents expressed concern about this risk, though a higher number showed moderate concern (53.6%), while 12.4% were highly concerned. However, 34% of the respondents did not take it as a matter that required attention. Also, more than half of the participants indicated that they would willingly participate in screening tests included in AMR surveillance programs if called upon, and a majority (77%) thought there was a need for better regulations on control of AMR. However, only 27 participants (27.8%) voiced their opinion on the kind of regulations that needed to be implemented. Of these, 22 (81.5%) provided single suggestions while 5 (18.5%) provided multiple. Recommendations from the 27 participants mostly revolved around creating more public awareness of the risk of AMR and safe ways of handling meat, especially those of

wild origin (13 participants; 40.6%, $n=32$). An emphasis was also put on equipping hunters with information as well as requiring mandatory use of PPE like gowns and gloves while handling wild boar meat to avoid cross-contamination (4 participants; 12.5%, $n=32$). Furthermore, 5 participants (15.6%, $n=32$) re-echoed the need for more stringent enforcement of legislations including inspection of all meat destined for human consumption (4 participants; 12.5%, $n=32$) and controlled prescription of antibiotics (2 participants; 6.3%, $n=32$). Moreover, some participants suggested a complete ban on the consumption of wild game (4 participants; 12.5%, $n=32$).

Practices related to AMR risk reduction

There were four hunters among the participants, and hunting was done weekly or rarely (seasonally). Most of the participants (68%) consumed wild boar meat although the consumption tendency appeared to be occasional. Most (61.9%) indicated that they consumed it rarely, while fewer numbers consumed it daily, weekly or monthly. Many of the participants (95.9%) ate only well-cooked wild boar meat, while 4.1% had eaten it raw or undercooked. More than half of the participants did not use any PPE while handling wild boar meat. However, 24.7% used it always, while 18.6% did it occasionally. Participant responses regarding practices and behaviors related to AMR risk reduction are summarized in Table 4.

Non-specific outcomes

Among the participants, nine (9.3%) reported that they have ever being diagnosed with infection with antibiotic-resistant bacteria, and six (6.2%) were unsure, while 82 (84.5%) had never been diagnosed with such an infection. Among those who got diagnosed with AMR bacteria, reported diagnoses included *Gardnerella vaginalis* resistant to metronidazole (1 participant), cystitis and urinary tract infections (3 participants), one of whom specified the UTI as an *E. coli* infection which was resistant to fluoroquinolones. One participant reported sore throat due to an unspecified causative agent, while four participants did not include a description of the diagnosed condition. All cases were reported to have been medically diagnosed. Five (55.6%, $n=9$) of those who reported infection were unsure of the source of their infection, while two (22.2%) thought they acquired it from public swimming facilities, one (11.1%) from meat and one (11.1%) thought it resulted from "wrong use of antibiotics".

Determinants of knowledge, attitudes and practices

Univariate linear regression analysis showed that the levels of knowledge among participants were significantly influenced by differences in sex, age and sector of occupation. The level of education did not have any influence on the level of knowledge. However, attitudes and practices were significantly influenced by all factors (Table 5).

The multivariable linear regression model (Table 6) predicted higher levels of knowledge among males than females, with males being three times more knowledgeable and four times better attitudes than females Levels of knowledge and better attitudes were higher among the younger participants than the older ones, with those within the age group of 26–35 years and 18–26 years being the most knowledgeable and with better attitudes towards AMR mitigation. Also, participants working in the public sector, as well as students, had better knowledge on AMR risks from wild boars, as well as better attitudes than the other sectors. The least levels of knowledge prevailed among the unemployed.

Questions	Response	Number	%
Are you a hunter?	Yes	4	4.1
	No	93	95.9
How frequently do you hunt wild boars?	Never	93	95.9
	Daily	0	0
	Weekly	2	2.1
	Monthly	0	0
	Rarely	2	2.1
Do you consume wild boar meat?	Yes	66	68
	No	31	32
How frequently do you consume wild boar meat?	Never	31	32
	Daily	1	1
	Weekly	1	1
	Monthly	4	4.1
	Rarely	60	61.9
Have you ever eaten raw or undercooked wild boar meat?	Yes	4	4.1
	No /1 do not eat wild boars	93	95.9
Do you use personal protective equipment while handling wild boar meat?	Always	24	24.7
	Sometimes	18	18.6
	No	55	56.7

Table 4. Status of practices of 97 participants from 8 Italian regions, in relation to AMR risk reduction from wild boar handling and consumption.

Variables	Category	Knowledge			Attitude			Practice	
		Poor	Moderate	Good	Negative	Neutral	Positive	Bad	Good
		N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
Sex	Female	46 (86.8)	2 (3.8)	5 (9.4)	34 (64.2)	14 (26.4)	5 (9.4)	0 (0)	53 (100)
	Male	37 (84.1)	5 (11.4)	2 (4.5)	24 (54.5)	14 (31.8)	6 (13.6)	5 (11.4)	39 (88.6)
P-value		< 0.001			< 0.001			< 0.001	
Age (Years)	18–25	16(88.8)	1(5.6)	1 (5.6)	4 (22.2)	11(61.1)	3 (16.7)	1 (5.6)	17 (94.4)
	26–35	19 (70.4)	3 (11.1)	5 (18.5)	18 (66.7)	5 (18.5)	4 (14.8)	0 (0)	27 (100)
	36–45	16 (84.2)	2 (10.5)	1(5.3)	15 (78.9)	3 (15.7)	1 (5.3)	2 (10.5)	17 (89.5)
	46–50	2 (0)	0 (0)	0 (0)	1 (50)	1 (50)	0 (0)	0 (0)	2 (100)
	> 50	30 (96.8)	1 (3.2)	0 (0)	20 (64.5)	8 (25.8)	3 (9.7)	2 (6.5)	29 (93.5)
P-value		< 0.001			< 0.001			< 0.001	
Level of Education	*Licenza elementare*	1 (100)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	1 (100)
	Licenza media	3 (100)	0 (0)	0 (100)	2 (66.7)	1 (33.3)	0 (0)	0 (0)	3 (100)
	Diploma	21 (87.5)	2 (8.3)	1(4.2)	10 (41.7)	10 (41.7)	4 (16.6)	2 (8.3)	22 (91.7)
	Laurea	51(86.4)	4 (6.8)	4 (6.8)	38 (64.4)	15 (25.4)	6 (10.2)	2 (3.4)	57 (96.6)
	Dottorato	7 (70)	1 (10)	2 (20)	8 (80)	1 (10)	1 (10)	1 (10)	9 (10)
P-value		0.530			0.0119			< 0.001	
Sector of occupation	Public	32 (80)	3 (7.5)	5 (12.5)	23 (57.5	13 (32.5)	4 (10)	1 (2.5)	39 (97.5)
	Private	17 (89.5)	2 (10.5)	0 (0)	14 (73.7)	3 (15.8)	2 (10.5)	3 (15.8)	16 (84.2)
	Student	20 (83.4)	2 (8.3)	2 (8.3)	12 (50)	10 (47.6)	2 (8.3)	0 (0)	24 (100)
	Unemployed	14 (100)	0 (0)	0 (0)	9 (64.3)	2 (14.3)	3 (21.4)	1 (7.1)	13 (92.9)
P-value		0.0356			< 0.001			< 0.001	

Table 5. Comparison of knowledge, attitudes and practices scores across different demographic categories of 97 survey participants from 8 regions of Italy (P-values based on univariate linear regression analysis).

Predictor	Category	Knowledge			Attitude			Practices		
		Effect size	95% CI	SE	Effect size	95% CI	SE	Effect size	95% CI	SE
Sex	Female	Ref								
	Male	3.8	-6.8–14.3	5.3	4	-5–13.5	4.7	-7.3	-12.2 – -2.4	2.4
Age	18–25	Ref								
	26–35	1.1	-16.8–19.1	10.3	-20.7	-36.9 – -4.5	5.8	6.9	-1.4–15.3	3.6
	36–45	-17.7	-40.8–5.5	12.8	-32.3	-53.2 – -11.4	8.1	3.8	-6.9–14.5	5.2
	46–50	-18.3	-59.5 – – 22.9	13.4	-38.7	-75.9 – -1.4	24.4	8.4	-10–27.5	12.5
	> 50	-15.4	-36.8–5.9	11.3	-29.5	-48.8 – -10.2	7.8	8	-1.9–17.9	4.9
Sector of occupation	Unemployed	Ref								
	Student	3.7	-18.7–26	11.1	-14.8	-35 – -5.4	9.81	-0.7	-11–9.7	5.6
	Public	15.9	-1–32.7	5.7	0.9	-14.3–16.2	9.1	1.0	-6.8–8.9	4.3
	Private	9.9	-9.7– 29.6	6.7	1.1	-16.6–18.9	9.9	-2.2	-11.3–7	5.1

Table 6. Multivariable linear regression analysis of the predictors of knowledge, attitudes and practices among 97 survey participants from 8 regions of Italy.

Good practices that promote AMR control were noted among the greatest proportion of participants. However, statistically, it was observed that females demonstrated seven times more satisfactory behaviors than males. Also, the older participants tended to have better practices than the young, with the 18–25-year-olds having the lowest practice scores, while those > 50 and 46–50-year-olds had the highest scores. Moreover, participants working in the public sector and the unemployed showed better tendencies to practice behaviors that mitigate the risk of spread of AMR than the other categories. Inadequate/bad practices were observed among students and those in the private sector.

There was a strong positive correlation between knowledge and attitude scores (=0.52) ($\tau = 0.52$, $P < 0.05$), but no correlation between knowledge and practices, or attitudes and practices ($\tau < 0.3$, $P > 0.05$).

Discussion

Wild boars have been reported to be carriers and possible transmitters of antibiotic-resistant bacteria[9,27]. The risk for transmission lies in environmental contamination (water sources, soils and plants) with excreta of infected animals, as well as consumption of contaminated animal products including meat[9,28]. Reducing the risk

of transmission and spread of resistant bacteria requires implementation of adequate infection prevention and control methods, whose success greatly depends on the willingness and ability of communities and individuals to correctly implement the recommended strategies[29,30]. This study provides a comprehensive analysis of the public perceptions and behaviors in eight regions of Italy regarding the consumption of wild boar meat in the context of AMR transmission and dissemination.

The results showed that a large proportion of the respondents (68%) consumed wild boar meat. This is comparable with survey reports in other parts of Europe including 68.7% in Czech Republic[31] and 86.2% in Poland[32]. Moreover, a study by Ferri, et al.[33] among Italian hunters reported wild boars as being the most consumed wild game, with an estimated consumption rate of 188 g per person per month. The high tendency towards consumption of wild boar meat could indicate popularity of this food source among the Italian population, and perhaps a long-standing culinary tradition. As reported by Di Bella, et al.[34], wild boar meat is appreciated for its nutritional value and as a more sustainable alternative to conventional meat. However, despite its popularity, in the present survey, it was observed that its consumption is largely seasonal, reflecting the hunting calendar (late October to January)[35,36]. Similar to reports by Fantechi, et al.[11], the tendency towards consumption of wild boar meat was more common among males than females. However, unlike the previous report, there was no marked difference in the wild boar meat consumption habits among different age groups.

It was noted that for most consumers, wild boar meat was accessed mostly in fresh form or minimally processed and consumed in various forms. The preference for very minimal to no processing of the meat may reflect a desire to preserve traditional flavors and recipes that could have been developed over centuries and passed down through generations, as is common in many traditional Italian regions[11]. Furthermore, hunters seem to be the main source of wild boar meat as reflected by most of the respondents sourcing the meat from hunters. They play a central role in the meat supply chain, either as direct providers or through informal distribution networks as reported by Gaviglio, et al.[37]. However, a section of respondents also indicated the presence of commercial sources of wild boar meat, which could indicate the co-existence of traditional supply chains and more formal market mechanisms. The study by Gaviglio, et al.[37] revealed a tendency of hunters to sell wild boar meat to local butchers, which evidently supports the claims of the respondents in this survey. However, in the previous study, this habit was prevalent among less than 7% of the hunters, therefore it is not expected that a large quantity of wild boar meat would be on sale in butcheries around Italy.

A significant proportion (77.3%) of the participants reported having received information on AMR. However, not all had been made aware of the potential risks of AMR transmission through consumption of contaminated wild boar meat. This gap highlights challenges in how information is communicated to the public in terms of clarity, simplicity and specificity of messages. A similar situation was observed during the EFSA-led "Safe2Eat" campaign across 17 countries in Europe in which 60% of the European population reported that they found food safety information too technical and difficult to comprehend[38]. Additionally, the knowledge gaps observed on the risk of AMR transmission through consumption and handling of meat could be a result of the lack of attention given to the topic by the relevant authorities. It has been observed that most AMR messaging have focused on infection prevention and control in hospital settings, while very minimal efforts have been made towards raising awareness regarding AMR risks from other sources including consumption of contaminated meat (game meat inclusive)[9]. In fact, alongside other misconceptions, it was noted that a significant number of participants did not believe that they could acquire resistant bacteria through consumption of wild boar meat. This belief is contrary to the reports of recent studies that have isolated resistant bacteria from wild boar meat, for example Rega, et al.[39] reported resistance to quinolones in 36.1% of *E. coli* isolated from wild boar meat. Furthermore, resistance genes including blaCMY-2 (54.3%), sul1 (38.9%), sul2 (30.9%), and tetG (24.6%) were detected in *E.coli* isolates from wild boars in the Tuscany region of Italy in a study by Bertelloni, et al.[18]. Moreover, a recent review by Akwongo, et al.[40] showed a significant prevalence of AMR bacteria in wild boars not only in Italy but also in other parts of the world in which wild boar populations are present. The misconceptions noted in this survey could be due to limited information available to the public, specifically on the role of wildlife, including wild boars in transmission of resistant bacteria[41].

Social media and formal education were highlighted as the major sources of information on AMR. This is typical of the current trend of information sharing where social media has emerged as a key tool for sharing information on various subjects[42,43]. If clear and concise content on AMR is developed and streamlined by experts, who already in this survey have been identified as veterinarians and medical personnel, they can leverage the current technology to reach a large section of the population with the right message for change. A project in northern Italy dubbed "This is public health," in collaboration with government agencies and hospitals utilized social media platforms under the names "Per la Salute di Tutti" to successfully reach communities with public health messages[44]. Educational institutions may be more accessible to those still in the school and university systems, mostly the young and especially those whose curricula include modules on AMR. A lack of uniformity in integration of AMR education in the university curricula in Italy was highlighted in a survey by De Vita, et al.[45]. Noteworthy, a substantial proportion of the population also relied on other sources including television, government agencies and work settings to access information on AMR. A mixed-media approach should therefore be incorporated in AMR messaging to capture all categories of people.

In this study, a large section of the respondents exhibited low levels of knowledge on the risk of transmission of AMR through consumption or handling of wild boar meat. This finding follows a similar trend with those observed in other studies in Italy on the topic of food safety, for example Licata, et al.[46] reported persistent gaps in knowledge on food safety among food handlers in Southern Italy. However, while low levels of knowledge and majority negative attitudes prevailed among the respondents, there was a positive correlation between the knowledge and attitude scores, which supports the general understanding that as awareness increases, so does a more favorable outlook towards AMR risk mitigation strategies[16]. There was however no correlation between knowledge and practices, or attitudes and practices. An overwhelming 94.8% of the participants were categorized

as demonstrating good practices. The observed disconnect between knowledge and practices may suggest that while people may perform routine hygiene practices, they are not sufficiently grounded in the understanding of how resistant bacteria can persist along the wild boar meat chain. Without this knowledge, crucial risk points such as cross-contamination during manipulation of wild boar carcasses or meat, or improper storage may be overlooked or wrongly applied[15,47]. Moreover, poor understanding of AMR may limit the community's ability to adopt more targeted preventive practices such as the use of gloves while handling uncooked meat, disinfection of contact surfaces and tools in between use, or even safe disposal of carcasses[16]. Furthermore, positive practices that emanate from habitual and not from risk awareness habits are often unsustainable as there is a risk that they are inconsistently applied or abandoned under different circumstances[48]. It is also worth noting that the discrepancy between knowledge and practices may reflect limitations inherent to self-reported data in including recall bias and social desirability bias[49]. Participants may have misremembered the frequencies or specifics of their handling and consumption behaviors, or they may have over-reported adherence to recommended safety practices to present themselves favorably. As a result, reported practices may not fully reflect actual behaviors, potentially obscuring the true relationship between knowledge and practice.

Males demonstrated significantly higher levels of knowledge on the AMR risk associated with wild boar meat and more positive attitudes towards risk mitigation than females. However, in terms of practices, females exhibited markedly more satisfactory behaviors, highlighting a gender-based divergence in the translation of knowledge into practice. This divergence could be attributed to differences in gender roles and socialization tendencies[50].

Younger participants, specifically those aged 18–25 and 26–35, were more knowledgeable and held better attitudes towards AMR control. This aligns with the findings on general AMR KAP studies by Vallin, et al.[51] in Sweden and Shatla, et al.[52] in Saudi Arabia. This trend could be attributed to greater exposure of the young to modern information channels such as social media and formal education. However, the practices were more satisfactory among older age groups, suggesting that experience and perhaps traditional food safety measures play a role in maintaining good practices. Several factors could contribute to the observed trends. First, the dissemination of information through social media and educational institutions might ensure that the younger, more digitally connected population gains access to knowledge about AMR. However, if the messaging is not tailored to practical applications, it might not translate to good practices for all demographics as highlighted in the "people-centered approach to tackling antimicrobial resistance" by WHO[53].

Public sector workers and students showed higher knowledge and attitude scores, possibly due to exposure to institutional training and interdisciplinary environments. This demographic group may have more access to government and research reports, including those on AMR, for example, Italy is currently one of the six European countries project benefitting from the EU4Health Programme, AMR-EDUCare that provides continuous professional development training on AMR for both clinical and non-clinical health workforce[54]. Also, governments and public health agencies often run educational campaigns and trainings that in most cases may be mandatory for public officials and students, especially regarding policy and regulations. Moreover, the collaborative interdisciplinary and interdepartmental nature of public work environments and academic settings may provide better opportunities for interaction between people of diverse professional backgrounds, which foster knowledge sharing.

While the present study provides valuable insights into the public's understanding (levels of knowledge), attitudes and practices in relation to AMR transmission risks through handling and consumption of wild boar meat in Italy, it presents limitations that should be acknowledged when interpreting its findings. The most significant constraint lies in the limited representativeness of the study population, as responses were obtained from participants from only eight of the 20 regions of Italy, with 81.4% residing in Campania, 6.2% in Lazio, 5.2% in Piemonte, 2.1% Lombardia and the rest 1% each. This uneven geographical distribution may bias the results towards regional practices, awareness levels and perceptions, thereby limiting the generalizability of the findings to the national context. Additionally, even though the minimum required sample size was achieved, statistical power of the study would have benefited from a higher number of participants, as the ability to draw robust comparisons across demographic or regional subgroups is limited by the small sample size. Finally, the cross sectional study design captures information from a single point in time and therefore cannot infer causal relationships or temporal changes in knowledge, attitudes and practices related to AMR transmission along the wild boar meat chain.

Conclusion

The study provides valuable insights into the interplay between individual attitudes, knowledge and public health behaviors concerning AMR in the context of wild boar meat consumption and handling. While there is a deficiency in knowledge regarding the risks of AMR transmission through consumption or handling of wild boars, and somewhat negative attitudes towards risk mitigation efforts among many participants, this does not necessarily translate into poor practices. These findings underscore the critical importance of public health strategies that go beyond simple information dissemination. For example, the absence of positive correlation between knowledge and practice means that current practices are not sufficiently informed by AMR risk, limiting the effectiveness of interventions and highlighting the need for educational efforts to raise awareness about the specific risks for transmission of AMR along the wild boar meat chain. Interventions must therefore be tailored to bridge the gap between awareness and behavioral implementation, considering the socio-demographic diversity of the population. This will ensure that AMR messaging is both accessible and actionable for all segments of society. Furthermore, strengthening public health messaging through accessible, multi-platform communication and integrating AMR education into formal and informal learning contexts will be essential to bridge the knowledge-practice gap and support effective risk mitigation. The suggested intervention strategies may hold promise but should be viewed as preliminary and hypothesis-generating rather

than conclusive. Their effectiveness must be assessed through more robust and targeted intervention research. Further investigations incorporating direct observation, behavioral verification or mixed methods approaches are also required to understand the mechanisms underlying the knowledge-practice gaps as they could provide more accurate assessment of practices and their linkage to knowledge, thereby strengthening understanding of AMR risk behaviors in these regions.

Data availability

Additional information about this study can be found in the supplementary documents submitted with this manuscript or by contacting the corresponding author.

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Author contributions

Claire Julie Akwongo, Maria Francesca Peruzy, Kurt Houf, Luca Borreli, Alessandro Fioretti and Nicoletta Murru were involved in the conceptualization of the study. Data collection was performed by Claire Julie Akwongo, Maria Francesca Peruzy and Nicoletta Murru, data analysis by Claire Julie Awongo, drafting and reviewing of the manuscript by Claire Julie Akwongo, Maria Francesca Peruzy, Kurt Houf, Luca Borreli, Alessandro Fioretti and Nicoletta Murru.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to M.F.P.

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