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Original Article

Status of Laboratory Biosafety and Biosecurity in Veterinary Research Facilities in Nigeria

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ABSTRACT

Background: This study determined current status of laboratory biosafety in Nigerian veterinary research facilities.
Methods: A questionnaire was developed to obtain information from researchers across Nigeria from July 2014 to July 2015. Information regarding demographics, knowledge of laboratory biosafety, availability and proper use of personal protective equipment (PPE), any priority pathogens researched, attitude on and use of standard laboratory practices, and biosafety awareness was obtained using a numeric scoring system. Data were analyzed with descriptive statistics, and univariate and multivariate logistic regression.
Results: A total of 74 participants from 19 facilities completed the questionnaire. General knowledge scores ranged from 3 to 28 (out of 28 possible points), with 94.6% of respondents receiving low scores (scores $<$ mean $+$ 1 standard deviation). Very few (17.6%) reported availability or use PPE. Many participants (63.5%) reported no access to biosafety level (BSL)-1–3 facilities. None reported availability of a BSL-4 facility. Knowledge scores pertaining to biosafety management practices ranged from 0 to 14 (out of 14 possible points) with 47.3% of respondents receiving good scores (scores $>$ mean $+$ 1 standard deviation). Only 16.2% of respondents (from four facilities) reported having biosafety officers. Rabies virus was the most researched pathogen (31.1% of respondents). The majority (71.6%) were unaware of laws guiding biosafety. Researchers [odds ratio (OR) = 18.0; 95% confidence interval (CI): 1.63, 198.5; $p = 0.023$], especially in BSL-2 (OR = 258.5; 95% CI: 12.71, 5256; $p < 0.001$) facility of research institute (OR = 25.0; 95% CI: 5.18, 120.6; $p < 0.001$), are more likely to have adequate access to and properly utilize biosafety devices and PPE.
Conclusions: Current knowledge of laboratory biosafety is limited except among a few researchers.

1. Introduction

Biosafety is a discipline that focuses on the safe handling and containment of infectious microorganisms and hazardous biological materials. Recently, research on infectious pathogens has been on the rise due to the emergence of new and re-emergence of previously identified infectious agents and diseases, some of which could be used as weapons of bioterrorism [1–3]. Laboratory researchers, including those working in veterinary facilities, are at risk of being exposed to infectious zoonotic agents. Zoonoses account for up to 61% of all contagious diseases affecting humans worldwide and also make up 75% of emerging human diseases [4]. Most infectious and zoonotic diseases usually start as anthroponoses—transmitted from lower vertebrates (primary sources) to humans. Anthroponoses,

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such as those involving the highly pathogenic avian influenza viruses, Lassa fever virus, *Brucella* spp., pathogenic *Mycobacterium* spp., *Bacillus anthracis, Escherichia coli* O157:H7, *Salmonella* spp., and rabies virus [5–12], typically cause serious health hazards among vast animal populations worldwide with the attendant economic and public health consequences being enormous [13]. The majority of these pathogens are on the Centers for Disease Control and Prevention (CDC) bioterrorism agents list [14].

Growing attention is being given to laboratory biosafety and containment of infectious agents [15] as most diseases caused by zoonotic agents are well-known and preventable. Laboratory biosafety and biosecurity are important in order to ensure researchers' safety, especially from laboratory acquired infections (LAIs), and to protect the public from accidental or intentional exposure to infectious pathogens [16]. These risks have raised a serious concern for the training of laboratory researchers [17]. Despite extensive documentation of the occurrence of LAIs causing disease and mortality among researchers [18] these infections still remain a problem. Due to scarce reports on LAIs in Nigerian veterinary research facilities, the magnitude of this problem remains largely unknown, thus hindering the ability to determine the best course of action to control the occurrence of LAIs.

Previous studies have focused on laboratory biosafety and biosecurity as it relates to laboratory technicians [19,20], clinical microbiology laboratories [20–22] medical diagnostic laboratories [23,24], and pharmaceutical and biotechnology laboratories [23] that work with human pathogens. Detailed studies on laboratory biosafety and biosecurity in Africa are uncommon [23,25]. In Nigeria, no study to date has assessed the state of biosafety and biosecurity in the few available veterinary research facilities. Despite reported outbreaks of highly infectious zoonotic pathogens [26–28] current information on the laboratory biosafety capabilities of existing veterinary research facilities working with these pathogens is unavailable. In this study, we surveyed researchers' knowledge of laboratory biosafety, the availability and proper use of biosafety equipment, the name and category of hazardous pathogens being studied, personal attitudes on and use of standard laboratory practices, and the level of biosafety awareness in veterinary facilities across Nigeria.

2. Materials and methods

2.1. Study design

A cross-sectional biosafety survey was carried out from July 2014 to July 2015. The target population included graduate students, academics, laboratory technologists, research officers, and veterinary clinicians working in veterinary research facilities across the six geopolitical zones of Nigeria. The sample size formula ($n = Z^2\ p\ (1 - p)\ /\ d^2$) for field study according to Thrusfield [29], where n is the computed sample size, Z is the degree of confidence (1.96 in this study), p is the expected proportion, and d is the desired absolute precision at the 95% confidence level (10% in this study), was used to obtain the target sample size. For this study, as we had no prior data regarding the proportion of researchers in veterinary facilities having a good laboratory knowledge score (defined as greater than one standard deviation above the mean), therefore, we set p at 50%. This gave a minimum sample size (n) of 96 respondents. To increase precision, 160 questionnaires were administered to respondents through a snowballing technique. This technique is a chain referral process in which respondents in veterinary facilities from the six geopolitical zones were asked to recommend other researchers until the desired sample size is met.

2.2. Questionnaire design and implementation

The questionnaire was comprised of two parts: demographic questions and general biosafety and biosecurity questions. Questions raised in our questionnaire were based on standards stipulated in international laboratory biosafety manuals such as the Biosafety in Microbiological and Biomedical Laboratories (BMBL) 5th Edition and the Laboratory Biosafety Manual (3rd Edition) developed by the World Health Organization (2014). In this study, questions indicative of respondents' general knowledge of laboratory biosafety, including issues such as biosecurity, biocontainment, decontamination protocols, biosafety levels and cabinets, standard operating procedures (SOPs), personal protective equipment (PPE), biohazard transport and disposal, and pest control, were asked. Also, respondents were asked about the availability and use of biosafety devices (such as facilities with the appropriate biosafety level and biosafety cabinets) and PPE. On PPE, we asked the respondents to list up to five of the basic PPE (such as lab coat, hand gloves, nose mask, hair net, face mask/safety goggles) they use when working with pathogens. If a respondent lists three to five PPE correctly, this is scored as good usage/availability. A list of two or fewer PPE is scored as poor usage/availability.

Respondents were further asked about their awareness of national laws regulating biosafety and select agents, as well as biosafety and biosecurity-related terms and regulatory associations both in Nigeria and globally. The questionnaire was pretested on five veterinary researchers from two veterinary faculties in the southwest and northcentral geopolitical regions of Nigeria.

The questionnaires were purposively administered to lecturers and laboratory technologists (irrespective of rank) carrying out research in Nigerian universities and colleges with veterinary faculties or units, veterinary research officers and technologists in various research laboratories at the National Veterinary Research Institute, veterinary clinicians with their own laboratories, and graduate students performing research in these facilities. Graduate students were typically enrolled in a PhD or Master's veterinary program and had at least 1 year's experience of conducting research in a veterinary research facility. Participating laboratories/respondents were purposively sampled based on their availability, veterinary research activity and/or presence of a veterinary research facility/laboratory. Consent was given by all participants and by the appropriate administrative personnel for all facilities where the questionnaire was distributed. Respondents were allowed to withdraw from the survey without penalty at any time. All supplied information was maintained confidential by the personnel administering the questionnaire and tabulating the results. The six Nigerian geopolitical zones from which researchers were enlisted were the northwest, northeast, northcentral, southwest, southeast, and south-south.

2.3. Data management and statistical analysis

Data were summarized using Microsoft Excel 2013 and analyzed using Open Source Epidemiologic Statistics for Public Health (OpenEpi), version 3.03a (http://www.openepi.com/Menu/OE_Menu.htm, updated 2015/05/04). A dependent/outcome variable was created for the following specific objectives that were used to determine the status of biosafety and biosecurity in Nigerian veterinary research facilities: (1) general knowledge of laboratory biosafety and biosecurity; (2) availability and proper use of biosafety devices and PPE; (3) management knowledge of biological safety; (4) breakdown of laboratory biosecurity; (5) attitude

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and adherence to standard laboratory practices; and (6) biosafety awareness level among researchers. Ranking of priority pathogens according to risk group and select agent status was done according to the United States Department of Agriculture and CDC criteria (available on the American Biological Safety Association website: https://my.absa.org/tiki-index.php?page=Riskgroups). Pathogens such as *Salmonella* spp. were observed to be categorized into two risk groups (2 and 3). The higher risk group levels were used in our analyses since the *Salmonella* spp. classified as risk group 3 pathogens were of animal origin.

A numeric scoring system was developed to assess general biosafety knowledge, the proper use of biosafety devices and PPE, the attitude of researchers and their adherence to standard laboratory practices, and the level of biosafety awareness. Cut-off points for good/high/satisfactory scores were defined as scores greater than mean + 1 standard deviation of the scores except where stated otherwise (Table 1). Descriptive and inferential statistics were then performed on the data. Chi-square analysis was used to test the association between demographic factors and outcome variables at the 95% confidence interval. Only variables displaying a significant association ($p < 0.05$ using the Fisher exact test) were subjected to likelihood multivariate logistic regression analysis to determine possible predicting factors (controlling for other covariates) for the status of biosafety and biosecurity in veterinary research facilities in Nigeria.

3. Results

3.1. Response rate

Of the 160 questionnaires distributed, 74 were retrieved from researchers, yielding a response rate of 46.5%.

3.2. Demographic information

The demographic information for the respondents is presented in Table 2. Respondents were predominantly male (77.0%) and had a mean age of 35.7 ± 6.9 years. Only a single respondent was older than 60 years. Respondents' occupations include all the three occupational categories from 19 different facilities across the country, although those working as academics (university or college) composed the greatest proportion (35.1%). The majority of respondents (68.9%) had < 10 years of experience in veterinary research facilities. Of the 74 participants in the survey, 73.1% reported that they conduct research in university or college laboratories. Respondents from all six geopolitical zones in Nigeria were represented, although most were from northcentral (28.4%), northwest (24.3%), and southwest (20.3%) regions.

Table 2
Demographic distribution of Nigerian students and researchers in veterinary research laboratories participating in a survey in 2014–2015

	n (%)
Age (y)	
20–39	57 (77.0)
40–59	16 (21.6)
≥ 60	1 (1.4)
Sex	
Male	54 (73.0)
Female	20 (27.0)
Occupation	
Student	13 (17.6)
Academic	26 (35.1)
Laboratory technologist	14 (18.9)
Researcher	10 (13.5)
Veterinary clinician	11 (14.9)
Facility type	
University/college laboratory	54 (73.0)
Research institute laboratory	12 (16.2)
Veterinary clinic laboratory	8 (10.8)
Biosafety level	
None	47 (63.5)
1	10 (13.5)
2	15 (20.3)
3	2 (2.7)
4	0 (0.0)
Years of service (y)	
1–5	39 (52.7)
6–10	25 (33.8)
11–15	8 (10.8)
16–20	2 (2.7)
Region in Nigeria	
Northwest	18 (24.3)
Northeast	8 (10.8)
Northcentral	21 (28.4)
Southwest	15 (20.3)
Southeast	7 (9.5)
South-south	5 (6.8)

3.3. General knowledge of laboratory biosafety and biosecurity

General knowledge scores ranged from 3 to 28 points (out of a possible score of 28 points). These scores were normally distributed with a mean of 19.1 ± 6.4 (Table 1). A majority (94.6%) of the respondents had poor general knowledge scores (Table 3).

3.4. Availability and proper use of biosafety devices and personal protective equipment

Less than one-fifth (17.6%) of the respondents reported that these devices were readily available and used appropriately (Table 3). Most of the respondents (79.7%) reported the use of PPE, although many (63.5%) had no access to facilities of any biosafety level; 13.5% used BSL-1, 20.3% used BSL-2, and only 2.7% (two respondents) used BSL-3 facilities. No respondent reported the

Table 1
Description of scores obtainable by respondents (outcomes)

	Minimum obtainable score	Maximum obtainable score	Mean ± standard deviation
General knowledge of laboratory biosafety and biosecurity	3	28	19.10 ± 6.38*
Availability and proper use of biosafety devices and personal protective equipment	0	13	5.38 ± 3.53*
Management knowledge of biological safety	0	14	3.84 ± 3.54*
Breakdown of laboratory biosecurity‡	0	2	1.60 ± 0.59†
Attitude and adherence to standard laboratory practices	0	15	7.42 ± 3.76*
Biosafety awareness level among researchers	0	10	2.88 ± 2.70*

* Good/Satisfactory scores = scores > mean + 1 standard deviation.
† Occurrence of biosecurity breakdown = scores > mean.
‡ Respondents were asked to indicate and explain if they have experienced any biosecurity issues in their facilities. Issues explained were verified and scored to be correct or not.

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Table 3
Status of laboratory biosafety and biosecurity in veterinary research facilities (parameters scored as a percentage)

	n (%)
General knowledge of laboratory biosafety and biosecurity	
Satisfactory knowledge	4 (5.4)
Poor knowledge	70 (94.6)
Availability and proper use of biosafety devices and personal protective equipment	
Good usage/availability	13 (17.6)
Poor usage/availability	61 (82.4)
Management knowledge of biological safety	
Satisfactory knowledge	35 (47.3)
Poor knowledge	39 (52.7)
Breakdown of laboratory biosecurity	
Had not occurred	55 (74.3)
Had occurred	19 (25.7)
Attitude and adherence to standard laboratory practices	
Good	22 (29.7)
Poor	52 (70.3)
Biosafety awareness level among researchers	
High	19 (25.7)
Low	55 (74.3)

Table 4
Classification of laboratory biosafety levels (BSL) of veterinary research facilities in Nigeria

Facility type	*n* (19)	BSL				
		None	1	2	3	4
University/college laboratory	11	✓	✓	✓	×	×
Research institute laboratory	1	✓	✓	✓	✓	×
Veterinary clinic laboratory	7	✓	×	×	×	×

✓, present; ×, absent.

availability of a BSL-4 facility (Table 4). Frequent nonusage of biosafety cabinets (BSCs) for research was reported (67.6%), while 9.5%, 21.6%, and 1.4% of respondents reported the availability and usage of BSC-1, BSC-2, and BSC-3 equipment, respectively.

3.5. Management knowledge of biological safety in veterinary research facilities

Knowledge scores pertaining to management practices ranged from 0 to 14, out of 14 possible points (Table 1), and were positively skewed (median = 3.00). Nearly half of the respondents (47.3%) received satisfactory scores (scores > mean + 1 standard deviation; Table 3). Of the 74 respondents, less than half (41.9%) had undergone training in laboratory biosafety, 44.6% had laboratory decontamination protocols in place, 47.3% had SOPs in use in their laboratories, 18.9% had their SOPs updated yearly, 39.2% had pest control procedures in place, 21.6% kept records of LAIs, 16.2% had records of the health history of research staff, 36.5% had received immunizations against potential agents of LAIs, 33.8% had occupational health and emergency response plans in place, 16.2% (from only four of the 19 facilities surveyed) had biosafety officers, and 14.9% had their laboratories accredited within the previous 3 years.

3.6. Priority pathogens categorized according to risk groups

Of the 74 respondents, more than two-thirds (73.0%) reported that they were more likely to be exposed to hazards from infectious pathogens than from chemicals in their veterinary research facilities. The largest proportion of respondents (33.8%) reported working with rodents; other respondents reported working with ruminants (cattle, sheep, and goats; 17.6%), small animals (dogs and cats; 13.5%), nonhuman primates (5.4%), poultry (4.1%), fish (2.7%), camels (2.7%), pigs (1.4%), rabbits (1.4%), and wildlife (1.4%). Some respondents (16.2%) did not report working with animals. A small number of respondents ($n = 8$ or 10.8%) reported working with highly infectious viral pathogens in risk group 4, including *peste de petits* ruminants virus (3 respondents, or 4.05%), Lassa fever virus (3 respondents, or 4.05%), and African swine fever virus (2 respondents, or 2.70%).

A larger proportion of survey respondents reported working with agents classified as risk group 3 pathogens (Fig. 1). The four most reported group 3 pathogens were rabies virus (23 respondents, 31.08%), *Brucella* spp. (19 respondents, 25.68%), *Salmonella* spp. (animal strains: 17 respondents, 22.97%), and pathogenic *Mycobacterium* spp. (15 respondents, 20.27%). Two respondents (2.70%) reported working with *Yersinia pestis*, and a single respondent (1.35%) reported working with the fungal pathogen *Histoplasma* spp.

The three most reported risk group 2 pathogens (Fig. 2) in this survey were *Staphylococcus* spp., including methicillin-resistant *Staphylococcus aureus* (14 respondents, or 18.94%), *E. coli* (13 respondents, 17.57%), and highly pathogenic avian influenza virus (13 respondents, 17.57%).

According to the United States Department of Agriculture and CDC criteria, eleven of the pathogens reported in this survey, researched in Nigerian veterinary facilities, are categorized as select agents (Fig. 3). These select agents are *Brucella* spp., *B. anthracis*, *Clostridium* spp., Lassa fever virus, *Mycoplasma mycoides*, and *Y. pestis*.

3.7. Breakdown of laboratory biosecurity

Approximately three-quarters of respondents (74.3%) reported no occurrence of breakdown, or failure of laboratory biosafety (Table 3). Of the respondents who reported the occurrence of biosafety breakdown, 70.0% cited the presence of laboratory biohazards associated with pathogenic agents.

3.8. Attitude and adherence to standard laboratory practices

Slightly more than one-quarter of the respondents (29.7%) reported a good attitude relating to standard laboratory practices (Table 3). The majority of respondents (68.9%) reported decontaminating or removing PPE upon exit from the research facility. Fewer respondents (21.6%) reported showering when exiting areas of the laboratory containing infectious material. Only 39.2% reported decontaminating equipment before removal from the research facility. Approximately half of the respondents (54.1%) reported autoclaving laboratory biowaste. A similar proportion (52.7%) were unaware of how biohazardous waste is transported for disposal, although 32.4% and 14.9% of respondents, respectively, reported the use of dedicated vehicles and/or vendors and wheelbarrows for disposal of waste. Half of the respondents (50.0%) reported incinerating biohazardous waste, while 31.1% reported disposing biohazardous waste in the general waste dumps.

3.9. Biosafety awareness among researchers

Overall, the biosafety awareness level is low. The percentage of respondents having low awareness level is 74.3% (Table 3). The majority of the respondents (71.6%) were unaware of national laws guiding biosafety and biosecurity in Nigeria. Few respondents reported being aware of the Cartagena protocol on biosafety (14.9%) and select agents (24.3%). More than half of the respondents (56.8% and 52.7%, respectively) reported being mindful of the BMBL and the Institutional Animal Care and Use Committee (IACUC) regulations. Respondents' awareness of the Nigerian Biological Safety Association (NiBSA; 21.6%), African Biological Safety Association

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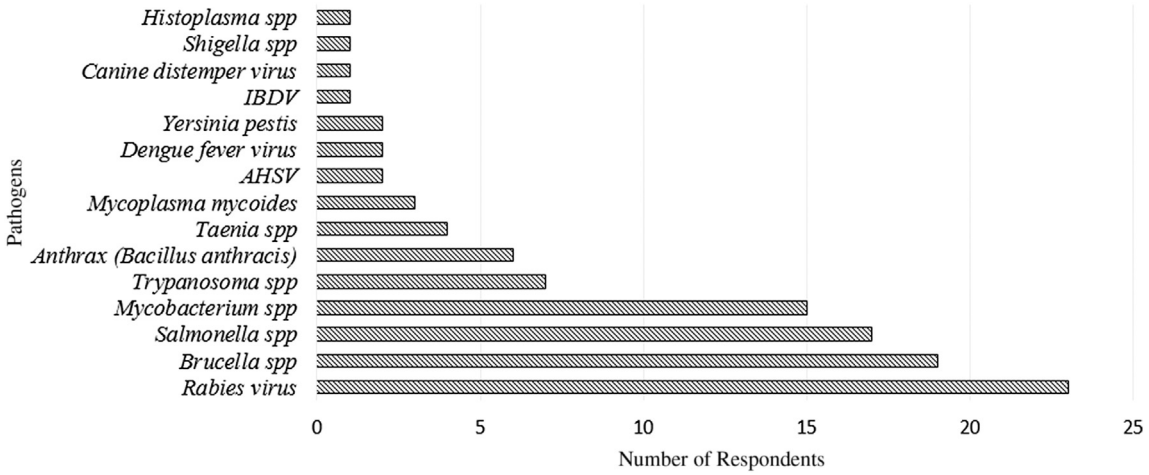

Fig. 1. Risk group 3 pathogens.
AHSV, African horse sickness virus; *IBDV*, Infectious Bursal Disease Virus.

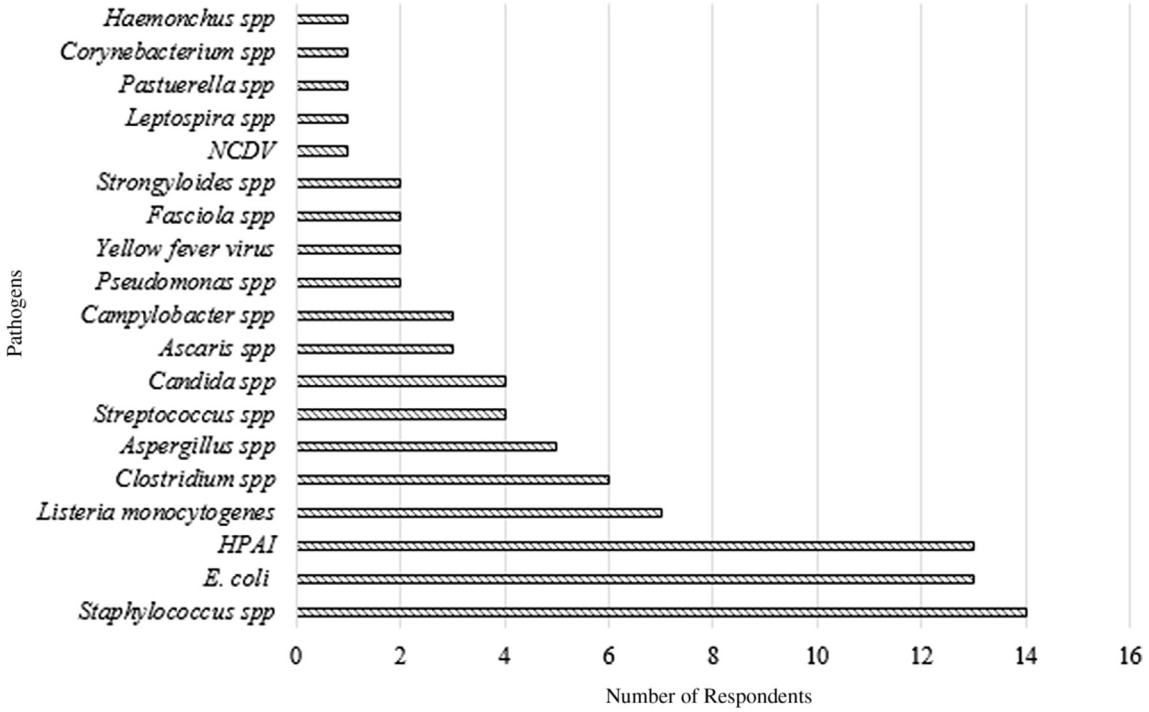

Fig. 2. Risk group 2 pathogens.
HPAI, Highly pathogenic avian influenza; *NCDV*, Newcastle disease virus.

(AfBSA; 16.2%), International Federation of Biosafety Associations (IFBA; 23.0%), and International Veterinary Biosafety Workgroup (IVBW; 27.0%) was low.

3.10. Factors associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria

Multivariate logistic regression analysis (Tables 5–8) revealed factors associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria. Men [odds ratio (OR) = 5.39; 95% confidence interval (CI): 1.59, 18.28; $p = 0.008$] are five times more likely to possess satisfactory management knowledge of biosafety (Table 5). In the occupation category (Table 6), researchers (OR = 18.0; 95% CI: 1.63, 198.5; $p = 0.023$) are far more likely to have adequate access to and properly utilize biosafety devices and PPE. However, veterinary clinicians are far more likely to experience breakdown of laboratory biosecurity (OR = 15.13; 95% CI: 2.28, 100.3; $p = 0.006$) despite having a high likelihood of biosafety awareness (OR = 9.63; 95% CI: 1.38, 67.24; $p = 0.043$). Respondents working in BSL-2 facilities (Table 7) are more likely have good usage (OR = 258.5; 95% CI: 12.71, 5256; $p < 0.001$) of the facility, satisfactory management knowledge of biosafety (OR = 36.62; 95% CI: 4.37, 307.2; $p < 0.001$) and good attitude and adherence to standard laboratory practices (OR = 6.33; 95% CI: 1.79, 22.39; $p = 0.008$). Research institute (Table 8) as a facility type has a high likelihood of being associated with good usage and availability of biosafety devices and PPE (OR = 25.0; 95% CI: 5.18, 120.6; $p < 0.001$), satisfactory management of biosafety (OR = 16.0; 95% CI: 1.925, 133; $p = 0.003$), and good attitude and adherence to standard laboratory practices (OR = 7.0; 95% CI: 1.79, 27.3; $p = 0.009$).

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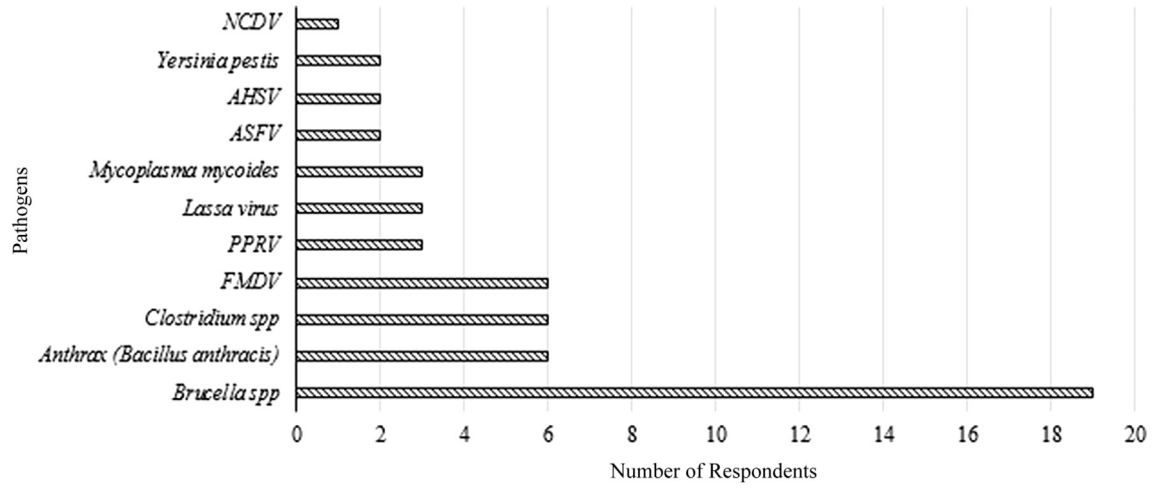

Fig. 3. Select agents according to USDA/CDC criteria.
AHSV, African horse sickness virus; *ASFV*, African swine fever virus; *FMDV*, Foot and mouth disease virus; *NCDV*, Newcastle disease virus; *PPRV*, Peste de petits ruminants virus.

Table 5
Likelihood multivariate logistic regression analysis of sex as a factor associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria

Sex	Management knowledge of biosafety		OR	95% CI	*p*
	Poor knowledge (%)	Satisfactory knowledge (%)			
Female	16 (21.6)	4 (5.4)	1.00		
Male	23 (31.1)	31 (41.9)	5.39	1.59, 18.28	0.008*

* Significant at $p < 0.05$.
CI, confidence interval; OR, odds ratio.

4. Discussion

This study revealed the level of negligence of laboratory biosafety and biosecurity in Nigerian veterinary laboratory facilities. We found that the majority of researchers have poor laboratory biosafety general knowledge scores, few report acceptable usage of biosafety devices and PPE, and many lack access to BSL-1–4 facilities, including BSCs. Also, despite the absence of BSL facilities, researchers continue to work with pathogens at all risk levels (1–4) including select agents, with rabies virus being the most researched high-risk pathogen nationwide. The overall awareness level of researchers regarding national and international laws and bodies pertaining to laboratory biosafety is low. We also found that certain occupations and facility types are predictors of good laboratory biosafety scores. To our knowledge, this survey is the first in Nigeria to evaluate the state of laboratory biosafety in veterinary facilities. Although the survey response rate of 46.5% is reasonable, not having a higher response rate may be due to inadequate motivation on the part of the respondents, which could also be indicative of the level of attention attached to laboratory biosafety. Poor knowledge scores received by the respondents signify a severe deficit in laboratory biosafety training and emphasize the urgent need to address this shortfall in the face of emerging and re-emerging zoonoses. Biosafety and biosecurity are compromised primarily in low-resource nations such as Nigeria [30]. In a survey of laboratory biosafety in India, Goswami et al [31] discovered that paramedical staff display a high level of biosafety knowledge. In addition to biosafety, biosecurity is also poorly implemented in Nigerian research facilities, which could create risks for researchers contracting LAIs. In any event of a breakdown in laboratory biosecurity, the public too are at possible risk of contracting infectious diseases. The proper use of containment devices, biosafety level facilities, and PPE are essential in preventing occupational infections [3].

Despite the majority of respondents reporting the use of PPE, there is often a lack of access to biosafety facilities and biosafety cabinets in veterinary facilities. As a result, those working on pathogens in risk groups 3 and 4 (especially rabies virus, *Brucella* spp., *B. anthracis*, *Mycobacterium* spp., *Y. pestis,* Lassa fever virus, and African swine fever virus), including several select agents, could be predisposed to contracting LAIs. Our findings are similar to those in a study by Oladeinde et al [24], which reported that most public and private human diagnostic laboratories in Nigeria lack biosafety cabinets. Whatever the setting, any lapse in laboratory biosecurity could seriously undermine public safety.

Management and administrative control of biological safety are integral parts of an effective biosafety program [30]. That less than half of respondents received satisfactory scores in the category of laboratory biosafety management provides additional evidence of poor biosafety and biosecurity knowledge in veterinary facilities in Nigeria. It is noteworthy that some researchers had completed laboratory biosafety training, and some laboratories had established decontamination protocols and SOPs, despite poor updating of SOPs. Gaudioso et al [32] found that biosafety training is routine in the US bioscience community. The importance of training laboratory researchers in biosafety and biosecurity [30] was emphasized in studies conducted by Goswami et al [31], Hakim et al [33] and Qasmi et al [34] in developing countries. Biosafety training and proper use of PPE also help guard against LAIs [35]. The low number of respondents and/or laboratories that reported controlling pests, keeping health records, receiving vaccinations, having occupational health and emergency response plans, having a biosafety officer(s), and achieving laboratory accreditation is a concerning deviation from standard practices and recommendations of international biosafety organizations. Vaccination plays an important role in limiting the incidence of infections with biological threat agents in occupationally exposed laboratory workers [35]. As a point of comparison 36.5% of respondents from Nigerian veterinary facilities reported receiving vaccinations while few (10%; $n = 25$) community health workers in Pakistan consistently receive immunization against the infectious agents handled in their laboratories [33]. Inadequate vaccination programs predispose laboratory workers and researchers to acquiring LAIs. In contrast to the developing world, research facilities in developed countries such as the USA [32] not only have biosafety officers

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Table 6
Likelihood multivariate logistic regression analysis of occupation as a factor associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria

Occupation	Availability and proper use of biosafety devices and PPE		OR	95% CI	*p*
	Low usage/availability (%)	Good usage/availability (%)			
Student	12 (16.2)	1 (1.4)	1.00		
Academic	23 (31.1)	3 (4.1)	1.56	0.15, 16.71	> 0.999
Laboratory technologist	12 (16.2)	2 (2.7)	2.00	0.16, 25.11	> 0.999
Researcher	4 (5.4)	6 (8.1)	18.0	1.63, 198.5	0.023*
Veterinary clinician	10 (13.5)	1 (1.4)	1.20	0.07, 21.72	0.717
Occupation	**Management knowledge of biosafety**				
	Poor knowledge (%)	Satisfactory knowledge (%)			
Student	7 (9.5)	6 (8.1)	1.00		
Academic	19 (25.7)	7 (9.5)	0.43	0.11, 1.73	0.399
Laboratory technologist	6 (8.1)	8 (10.8)	1.56	0.34, 7.11	0.853
Researcher	1 (1.2)	9 (12.2)	10.5	1.02, 108.6	0.075
Veterinary clinician	6 (8.1)	5 (6.8)	0.97	0.19, 4.87	> 0.999
Occupation	**Breakdown of laboratory biosecurity**				
	Had not occurred (%)	Had occurred (%)			
Student	11 (14.9)	2 (2.7)	1.00		
Academic	20 (27.0)	6 (8.1)	1.65	0.28, 9.60	0.913
Laboratory technologist	12 (16.2)	2 (2.7)	0.92	0.11, 7.67	> 0.999
Researcher	8 (10.8)	2 (2.7)	1.38	0.16, 11.94	> 0.999
Veterinary clinician	4 (5.4)	11 (14.9)	15.13	2.28, 100.3	0.006*
Occupation	**Biosafety awareness**				
	Low (%)	High (%)			
Student	11 (14.9)	2 (2.7)	1.00		
Academic	20 (27.0)	6 (8.1)	1.65	0.28, 9.60	0.621
Laboratory technologist	12 (16.2)	2 (2.7)	0.92	0.11, 7.67	> 0.999
Researcher	8 (10.8)	2 (2.7)	1.38	0.16, 11.94	> 0.999
Veterinary clinician	4 (5.4)	7 (9.5)	9.63	1.38, 67.24	0.043*
Occupation	**Attitude and adherence to standard laboratory practices**				
	Poor (%)	Good (%)			
Student	11 (14.9)	2 (2.7)	1.00		
Academic	23 (31.1)	3 (4.1)	0.72	0.10, 4.93	> 0.999
Laboratory technologist	7 (9.5)	7 (9.5)	5.50	0.88, 34.46	0.075
Researcher	4 (5.4)	6 (8.1)	8.25	1.15, 59.00	0.073
Veterinary clinician	7 (9.5)	4 (5.4)	3.14	0.45, 21.96	0.479

* Significant at $p < 0.05$.
CI, confidence interval; OR, odds ratio; PPE, personal protective equipment.

available, but these officers also conduct routine risk assessments in their laboratories.

Pathogens from all four risk groups, with some also having select agent status, were studied by respondents to our survey. Rabies virus—a risk group 3 pathogen—was studied by the greatest percentage of respondents. This is consistent with the findings of Ng and Sargeant [4], who prioritized rabies highest and second among zoonotic diseases in Canada and the USA, respectively in a survey of health professionals. Other zoonotic pathogens studied by respondents to our survey have been implicated as potential occupational hazards and public health threats, including *Brucella* spp. *B. anthracis* (the causative agent of anthrax), *Salmonella* spp., pathogenic *Mycobacterium* spp., *Y. pestis* and *Histoplasma* spp. *B. anthracis* is an important pathogen causing LAI at high infective doses but it can be prevented by personal protective measures and adequate training in laboratory biosafety [35]. We found that respondents to our survey worked with a diverse range of animal species that included rodents, cattle, sheep and goats, dogs, cats, fish, camels, pigs, rabbits, wildlife, and non-human primates. Although the reported rate for breakdown of laboratory biosecurity remains low, inadequate biosafety and biosecurity standards could facilitate transmission of zoonoses from multiple animal species to researchers and the public. Our results indicate that greater attention should be paid to laboratory biosafety and biosecurity in Nigeria, as at least seven major select agents (*Brucella* spp., *B. anthracis*, *Clostridium* spp., Lassa fever virus, *M. mycoides*, and *Y. pestis*) are studied in Nigerian laboratories, despite the poor state of laboratory biosafety.

The majority of the respondents to our survey described having a poor attitude related to standard laboratory practices. Wearing PPE was reported to be the most routinely used biosafety practice in a survey of research laboratories in various parts of the world [23]. Encouragingly, the majority of respondents in our study reported routine use of PPE. Low compliance of laboratory workers with the use of PPE and biosafety cabinets was found to be associated with acquiring LAIs such as brucellosis [36]. Although a good percentage (51, 68.9%) of researchers reported routinely decontaminating or removing PPE upon exit from their research facilities,

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Table 7
Likelihood multivariate logistic regression analysis of biosafety level (BSL) as a factor associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria

	Availability and proper use of biosafety devices and PPE		OR	95% CI	*p*
BSL	Low usage/Availability (%)	Good usage/Availability (%)			
None	47 (63.54)	0 (0.0)	1.000		
1	10 (13.5)	0 (0.0)	4.700	0.09, 251.2	> 0.999
2	4 (5.4)	11 (14.9)	258.5	12.71, 5256	< 0.001*
3	0 (0.0)	2 (2.7)	376.0	5.83, 24270	0.006*
4	0 (0.0)	0 (0.0)	94.0	0.77, 11530	> 0.999
	Management knowledge of biosafety				
BSL	Poor knowledge (%)	Satisfactory knowledge (%)			
None	34 (46.0)	13 (17.6)	1.00		
1	4 (5.4)	6 (8.1)	3.92	0.95, 16.19	0.115
2	1 (1.4)	14 (18.9)	36.62	4.37, 307.2	< 0.001*
3	0 (0.0)	2 (2.7)	10.46	0.44, 247.6	0.297
4	0 (0.0)	0 (0.0)	2.62	0.05, 138.8	> 0.999
	Attitude and adherence to standard laboratory practices				
BSL	Poor (%)	Good (%)			
None	38 (51.4)	9 (12.2)	1.00		
1	8 (10.8)	2 (2.7)	1.06	0.19, 5.84	> 0.999
2	6 (8.1)	9 (12.2)	6.33	1.79, 22.39	0.008*
3	0 (0.0)	2 (2.7)	16.89	0.70, 407.3	0.161
4	0 (0.0)	0 (0.0)	4.22	0.08, 227.4	> 0.999

* Significant at $p < 0.05$.
CI, confidence interval; OR, odds ratio.

Table 8
Likelihood multivariate logistic regression analysis of facility type as a factor associated with the status of biosafety and biosecurity in veterinary research facilities in Nigeria

	Availability and proper use of biosafety devices and PPE		OR	95% CI	*p*
Facility type	Low usage/availability (%)	Good usage/availability (%)			
University/College laboratory	50 (67.6)	4 (5.4)	1.00		
Research institute laboratory	4 (5.4)	8 (10.8)	25.0	5.18, 120.6	< 0.001*
Veterinary clinic laboratory	7 (9.5)	1 (1.4)	1.79	0.17, 18.35	> 0.999
	Management knowledge of biosafety				
Facility type	Poor knowledge (%)	Satisfactory knowledge (%)			
University/College laboratory	32 (43.2)	22 (29.7)	1.00		
Research institute laboratory	1 (1.4)	11 (14.7)	16.0	1.925, 133	0.003*
Veterinary clinic laboratory	6 (8.1)	2 (2.7)	0.48	0.09, 2.63	0.659
	Attitude and adherence to standard laboratory practices				
Facility type	Poor (%)	Good (%)			
University/College laboratory	42 (56.8)	12 (16.2)	1.00		
Research institute laboratory	4 (5.4)	8 (10.8)	7.00	1.79, 27.3	0.010*
Veterinary clinic laboratory	6 (8.1)	2 (2.7)	1.17	0.21, 6.54	> 0.999

* Significant at $p < 0.05$.
CI, confidence interval; OR, odds ratio; PPE, personal protective equipment.

far fewer (16, 21.6%) reported showering out of infectious areas in the laboratory and decontaminating equipment before removal from the research facility. There is also a lack of awareness on how biohazardous waste generated in laboratories is transported for disposal. The common practices of using dedicated vehicles and/or vendors and wheelbarrows to transport biohazardous waste and disposing of waste in general landfills should be discouraged. Instead, the less hazardous practice of incinerating biohazard waste should be encouraged. Our findings are comparable to results obtained from a survey of the laboratories of 250 community health workers in Pakistan [33], where 30% of laboratory researchers reported use of PPE when carrying out microbiological work, 85.2% reported washing hands during laboratory procedures, 32.2% of laboratories reported having policies for the safe handling of sharps, and 70% routinely decontaminated work surfaces and had pest control programs.

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Despite the highly publicized principles and practices of laboratory biosafety and biosecurity emphasized in international agreements such as the Cartagena protocol [37], the situation in Nigerian veterinary research facilities remains inadequate. The poor awareness level of respondents concerning national and global laws guiding biosafety, select agents, and other terms and associations (NiBSA, AfBSA, IFBA, BMBL, IACUC, and IVBW) related to biosafety and biosecurity point to a deficit of laboratory biosafety knowledge in Nigeria. Researchers in Nigerian veterinary facilities were somewhat familiar with BMBL and IACUC because of the nature of the pathogens studied and diverse animal species used as models. A majority of the respondents (71.6%) were unaware of national laws guiding biosafety and biosecurity in Nigeria. In 2015, the Nigerian government passed a biosafety bill into law, yet the majority of survey respondents remain unaware of this law. Even with widespread unawareness, this law is inadequate as it only addresses certification of genetically modified organisms (GMO) in food products for human health and in the environment, prohibiting the indiscriminate introduction of GMOs into circulation. No provision in the new law was made for laboratory biosafety.

We cannot ascertain the status of laboratory biosafety in other countries in the African continent (due to dearth of information) but we speculate that the state (in most countries) is not too different from what is observed in Nigeria. Some countries such as Burundi, Democratic Republic of Congo, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda have biosafety regulations in place [38]. However, these laws/acts are mainly GMO focused and lacking in the laboratory biosafety component. Most university research laboratories in Africa are of BSL-1 while some research institutes have BSL-2 and lower status BSL-3 (KEMRI 5 BSL-3) facilities. Few specialized BSL-3 facilities are available; for example: Naval Medical Research Unit No. 3, Cairo, Egypt; University of Nairobi/University of Manitoba BSL-3 facility in Nairobi, Kenya; and the National Veterinary Research Institute, Vom, Nigeria. Only two BSL-4 facilities are in the continent: Centre International de Recherches Médicales de Franceville, Franceville, Gabon; and the National Institute for Communicable Diseases, Grahamstown, South Africa.

The results of our multivariate logistic regression analysis revealed that good knowledge of laboratory biosafety in Nigerian veterinary facilities is more likely to be associated with male researchers and those working in research institute laboratories. The observation that male researchers demonstrated high knowledge scores is expected as more male respondents (25/54) had received training on laboratory biosafety than female respondents (6/20) and also had (13/54) work experience greater than 10 years than female researchers (2/20) that participated in the survey. Our results also show that respondents working in research institutes demonstrate greater biosafety knowledge than those working in other veterinary research facilities. Greater biosafety knowledge is reflected in the observation that researchers and research institute (facility type) are also predictive factors associated with adequacy and proper usage of biosafety devices and PPE, a good attitude towards biosafety, and adherence to standard laboratory practices. The decreased likelihood of veterinary clinic laboratories experiencing a breakdown of biosafety or having a low awareness of biosafety is expected. Limited research is being conducted in these laboratories and biosafety principles are not typically maintained, as few, if any, certification bodies are available to accredit these laboratories. We emphasize that research on highly infectious pathogens should be restricted to laboratories with the experience and capability to handle the agents [35].

Our study is not without limitations. We employed a convenient sampling method, as only researchers in veterinary facilities were interviewed, with the respondents identified using a snowballing technique in which only interested researchers were approached. We believe our sampling method does not affect the external validity of our results as this approach is common in observational studies. Another limitation is our inability to sample up to the calculated size of 96. The size of 74 respondents we sampled is reasonable because there are few veterinary research laboratories in the country. Most veterinary research is limited to laboratories present in veterinary schools (there are fewer than 10 universities in Nigeria with accredited veterinary faculties) and the National Veterinary Research Institute. Also, responses from the remaining 22 might not have affected observed responses significantly. The geographic distribution of respondents was expected and is reflective of the distribution of researchers in the few available veterinary research facilities across Nigeria. In addition, the information provided by the respondents cannot be confirmed, potentially affecting our outcome variables and introducing bias. This risk was mitigated by asking certain questions in different ways to confirm earlier answers and eliminate inconsistencies.

This study revealed that current knowledge of laboratory biosafety and biosecurity in Nigerian veterinary research facilities is limited except among a very few researchers. There is inadequate availability of and access to biosafety devices and PPE, as well as a low awareness level by researchers regarding national and international laws and associations pertaining to laboratory biosafety. Due to the recent outbreaks of highly infectious agents in West Africa (Nigeria inclusive), Nigeria should be at the forefront of carrying out risk assessments. A national reporting system for LAIs and a National Biosafety and Biosecurity Strategic Plan (in terms of situation alerts, emergency preparedness, and response) should be developed. There should also be a national classification of microorganisms by risk group (defined by pathogenicity, mode of transmission/host range, and local availability of effective preventive and treatment measures). Current laws on biosafety should be redressed to include a laboratory biosafety component and should conform to guidelines and policies existing in international biosafety manuals. We advocate the provision of biosafety devices in veterinary research laboratories across Nigeria, with greater attention focused on training and re-training of research scientists in biosafety and biosecurity. There is a need for continuous investment in research infrastructure into which biosafety facilities are well incorporated. We are also calling for the development, promotion, and maintenance of a laboratory biosafety and biosecurity culture through the education of researchers, laboratory technologists, veterinary practitioners, and other stakeholders. The NiBSA should be fortified to effectively champion the cause of advancing biosafety and biosecurity across the nation.

Conflicts of interest

We declare no conflict of interest.

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References

[1] Nulens E, Voss A. Laboratory diagnosis and biosafety issues of biological warfare agents. Clin Microbiol Infect 2002;8:455–66.
[2] Pedrosa PBS, Cardoso TAO. Viral infections in workers in hospital and research laboratory settings: a comparative review of infection modes and respective biosafety aspects. Int J Infect Dis 2011;15:e366–76.
[3] Coelho AC, García Díez J. Biological risks and laboratory-acquired infections: a reality that cannot be ignored in health biotechnology. Front Bioeng Biotechnol 2015;3:1–10.
[4] Ng V, Sargeant JM. A quantitative approach to the prioritization of zoonotic diseases in North America: a health professionals' perspective. PLoS One 2013;8:e72172.
[5] Alhaji NB, Odetokun IA. Assessment of biosecurity measures against highly pathogenic avian influenza risks in small-scale commercial farms and free-range poultry flocks in the northcentral Nigeria. Trans Emerg Dis 2011;58:157–61.
[6] Sogoba N, Feldmann H, Safronetz D. Lassa fever in West Africa: evidence for an expanded region of endemicity. Zoonoses Public Health 2012;59:43–7.
[7] Levings RL. Emerging and exotic zoonotic disease preparedness and response in the United States—coordination of the animal health component. Zoonoses Public Health 2012;59:80–94.
[8] Boukary AR, Thys E, Rigouts L, Matthys F, Berkvens D, Mahamadou I, Yenikoye A, Saegerman C. Risk factors associated with bovine tuberculosis and molecular characterization of *Mycobacterium bovis* strains in urban settings in Niger. Trans Emerg Dis 2012;59:490–502.
[9] Goel AK. Anthrax: a disease of biowarfare and public health importance. World J Clin Cases 2015;3:20–33.
[10] Murphy M, Buckley JF, Whyte P, O'Mahony M, Anderson W, Wall PG, Fanning S. Surveillance of dairy production holdings supplying raw milk to the farmhouse cheese sector for *Escherichia coli* O157, O26 and O111. Zoonoses Public Health 2007;54:358–65.
[11] Cummings KJ, Rodriguez-Rivera LD, Grigar MK, Rankin SC, Mesenbrink BT, Leland BR, Bodenchuk MJ. Prevalence and characterization of *Salmonella* isolated from feral pigs throughout Texas. Zoonoses Public Health 2016;63:436–61.
[12] Servat A, Herr J, Picard-Meyer E, Schley L, Harbusch C, Michaux C, Pir J, Robardet E, Engel E, Cliquet F. First isolation of a rabid bat infected with European bat lyssavirus in Luxembourg. Zoonoses Public Health 2013;62:7–10.
[13] Yeh JY, Park JY, Cho YS, Cho IS. Animal biowarfare research: historical perspective and potential future attacks. Zoonoses Public Health 2012;59:536–44.
[14] Centres for Disease Control and Prevention. Bioterrorism agents/diseases. Emergency preparedness and response [Internet]. 2015 [cited 2015 Dec 28]. Available from: http://emergency.cdc.gov/agent/agentlist.asp.
[15] Nordmann BD. Issues in biosecurity and biosafety. Int J Antimicrob Agents 2010;36(Suppl 1):S66–9.
[16] Gaudioso J, Zemlo T. Survey of bioscience research practices in Asia: implications for biosafety and biosecurity. Appl Biosaf 2007;12:260–7.
[17] Chamberlain AT, Burnett LC, King JP, Whitney ES, Kaufman SG, Berkelman RL. Biosafety Training and incident-reporting practices in the United States: a 2008 survey of biosafety professionals. Appl Biosaf 2009;14:135–43.
[18] Pike RM. Laboratory-associated infections: summary and analysis of 3921 cases. Health Lab Sci 1976;13:105–14.
[19] Zavery J. Knowledge, attitudes and practice of laboratory technicians. Natl J Med Res 2012;2:113–5.
[20] Deveci O, Tekin R, Aslan E, Hosoglu S, Bozkurt F, Dayan S, Demirpence Ö. Assessment of the laboratory transmission of brucellosis in an endemic region. Acta Med Mediterranea 2014;30:205–8.
[21] Ergönül Ö, Çelikbaş A, Tezeren D, Güvener E, Dokuzoğuz B. Analysis of risk factors for laboratory-acquired brucella infections. J Hosp Infect 2014;56:223–7.
[22] Bouza E, Sánchez-Carrillo C, Hernangómez S, José González M. Laboratory-acquired brucellosis: a Spanish national survey. J Hosp Infect 2005;61:80–3.
[23] Astuto-gribble LM, Gaudioso JM, Caskey SA, Zemlo TR. A survey of bioscience research and biosafety and biosecurity practices in Asia, Eastern Europe, Latin America, and the Middle East. Appl Biosaf 2009;14:181–96.
[24] Oladeinde BH, Omoregie R, Odia I, Osakue EO, Imade OS. Biorisk assessment of medical diagnostic laboratories in Nigeria. Saf Health Work 2013;4:100–4.
[25] Kirunda H, Otimonapa M. Low level of awareness in biosafety and biosecurity among professionals in Uganda: a potential risk in the dual-use dilemma. J Bioterror Biodef 2014;5:1–10.
[26] Ducrotoy MJ, Bertu WJ, Ocholi RA, Gusi AM, Bryssinckx W, Welburn S, Moriyón I. Brucellosis as an emerging threat in developing economies: lessons from Nigeria. PLoS Negl Trop Dis 2014;8:e3008.
[27] Fasina FO, Shittu A, Lazarus D, Tomori O, Simonsen L, Viboud C, Chowell C. Transmission dynamics and control of Ebola virus disease outbreak in Nigeria, July to September 2014. Euro Surveill 2014;19:1–8.
[28] Althaus CL, Low N, Musa EO, Shuaib F, Gsteiger S. Ebola virus disease outbreak in Nigeria: transmission dynamics and rapid control. Epidemics 2015;11:80–4.
[29] Thrusfield M. Veterinary epidemiology. 3rd ed. Oxford (UK): Blackwell Publishing; 2009. 626 p.
[30] Heckert RA, Reed JC, Gmuender FK, Ellis M, Tonui W. International biosafety and biosecurity challenges: suggestions for developing sustainable capacity in low-resource countries international biosafety and biosecurity. Appl Biosaf 2011;16:223–30.
[31] Goswami HM, Soni ST, Patel SM, Patel MK. A study on knowledge, attitude and practice of laboratory safety measures among paramedical staff of laboratory services. Natl J Community Med 2011;2:470–3.
[32] Gaudioso J, Rivera SB, Caskey S, Salerno RM. Laboratory biosecurity: a survey of the U.S. bioscience community. Appl Biosaf 2006;11:138–43.
[33] Hakim ST, Nadeem SG, Muhammad S, Tayyab H. Knowledge and awareness of routine biosafety measures and proper waste disposal practices among healthcare workers in Karachi, Pakistan. Appl Biosaf 2012;17:1–5.
[34] Qasmi SA, Khan E, Maqbool AZ. Survey of biorisk management in clinical laboratories in Karachi, Pakistan. Appl Biosaf 2012;17:198–207.
[35] Rusnak JM, Kortepeter MG, Hawley RJ, Anderson AO, Boudreau E, Eitzen E. Threat agents in unvaccinated laboratory workers. Biosecur Bioterror 2004;2:281–93.
[36] Sayin-Kutlu S, Kutlu M, Ergonul O, Akalin S, Guven T, Demiroglu YZ, Acicbe O, Akova M. Laboratory-acquired brucellosis in Turkey. J Hosp Infect 2012;80:326–30.
[37] Jank B, Gaugitsch H. Decision making under the Cartagena Protocol on Biosafety. Trends Biotechnol 2001;19:194–7.
[38] Mtui G. Biosafety systems in Eastern and Central Africa. Afr J Environ Sci Technol 2012;6:80–93.

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