Journal of Population Therapeutics & Clinical Pharmacology

Preparedness for Emerging Infectious Diseases Among Biomedical Engineers and Clinical Laboratory Scientists in Saudi Arabia: A Cross-Sectional Study

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Abstract
Emerging infectious diseases pose a serious public health threat globally. Healthcare workers are vulnerable to acquiring and transmitting new infections if proper infection control practices are not followed. This cross-sectional study assessed the preparedness for emerging infectious diseases among 389 biomedical engineers and clinical laboratory scientists from major cities in Saudi Arabia using a survey. Overall knowledge was low (59%) and self-reported practices suboptimal. Major gaps included lack of job-specific training, low risk perception, and inadequate understanding of recommended precautions for handling potentially infectious specimens and decontaminating medical equipment. Multivariate regression found older age, more experience, and prior infection control training to be predictors of higher knowledge. Job-specific training was the strongest factor associated with good practices. The findings indicate the need for improved education and training of biomedical engineers and laboratory scientists to strengthen Saudi Arabia's capacity for early detection and response to infectious disease outbreaks. Targeted interventions should focus on building applied understanding of transmission risks and infection control principles.

Introduction
New infectious diseases have emerged and spread globally at an unprecedented rate in recent decades. Examples include HIV, SARS, MERS, Ebola, Zika, and most recently, COVID-19 (WHO, 2017). The increased incidence of epidemics and pandemics is attributed to several factors including increased travel and trade, urbanization, climate change, interaction between humans and animals, and exploitation of the natural environment (Morens et al., 2004; Morse, 1995). Many new pathogens originate in animals before crossing over to infect humans, known as zoonotic diseases (Taylor et al., 2001). Overall, 60% of emerging infectious diseases and 75% of recent epidemics have been zoonotic (WHO, 2017).
Emerging infectious diseases spread rapidly due to lack of preexisting immunity in human populations. They can have high case fatality rates given the absence of effective treatments or vaccines (Igbinosa et al., 2021). The unveiling of a novel pathogen also creates uncertainty regarding transmission patterns, clinical severity, and appropriate control measures. This underscores the critical need for effective surveillance and emergency preparedness to enable rapid detection and containment of outbreaks before they spiral out of control.

Healthcare workers are disproportionately vulnerable to acquiring and propagating emerging infections within healthcare facilities if appropriate infection prevention and control practices are not implemented and strictly followed (Singh et al., 2019). During the 2003 SARS epidemic, over 20% of cases globally occurred in healthcare workers (WHO, 2003). Both MERS and Ebola also led to high rates of infection among medical personnel due to breaches in infection control (WHO, 2015; Zumla & Hui, 2014). Transmission risks are especially high when handling specimens collected from infected patients or contaminated equipment without adhering to recommended precautions.

Laboratory professionals play a pivotal role in detecting and diagnosing novel pathogens. However, the handling, transport and analysis of clinical specimens also poses significant infection risks if proper biosafety protocols are not followed (Baron et al., 2014). Likewise, biomedical engineers are charged with servicing and maintaining potentially contaminated patient care equipment. use of personal protective equipment (PPE) and adherence to disinfection procedures is paramount to prevent inadvertent exposure (CDC, 2009).

Evaluating the knowledge, attitudes, practices, and training related to infection control among healthcare workers can identify strengths and gaps to guide improvements in pandemic preparedness. While studies have surveyed doctors and nurses in this regard (Koh et al., 2005; Tan et al., 2020), fewer have focused on clinical laboratory staff and biomedical engineers. This is an important gap given their frontline role during outbreaks.

Saudi Arabia has direct experience responding to novel infectious diseases when MERS-coronavirus emerged in 2012 (Al-Abdallat et al., 2014). However, preparedness assessments specific to laboratory scientists and biomedical engineers working in the Kingdom are lacking. This study aimed to fill this gap by surveying these two high-risk cadres to evaluate their current state of readiness to handle emerging infectious disease events in Saudi Arabia.

Literature Review

Outbreaks of new infectious diseases are a major threat to global public health and economic stability. Over the past few decades, the incidence and diversity of epidemics has increased significantly. Morse (1995) warned that humankind was entering a new "era of emerging infections" due to ecological, environmental and demographic changes. Morens et al. (2004) described the "global 'superhighway' of travel and commerce" as a driver of rapid international spread before public health responses can be mobilized.

The U.S. Centers for Disease Control and Prevention (CDC) defines an emerging infectious disease as "an infectious disease that has newly appeared in a population or has existed but is rapidly increasing in incidence or geographic range" (2012). Emerging pathogens are those newly identified or previously unknown and undetected. Re-emerging diseases are those that reappear after significant decline. SARS in 2003, MERS in 2012, and COVID-19 in 2019 exemplify the continued threat of novel, highly transmissible respiratory viruses emerging in humans (WHO, 2017).

Zoonotic transmission from animals is responsible for the majority of emerging human infections. Wild animals and livestock serve as reservoirs from which new pathogens can cross species to infect human populations (Morse et al., 2012). Taylor et al. (2001) found that nearly three-fourths of emerging infectious diseases originated from animals. Bats are an especially important reservoir playing a major role in SARS, MERS and Ebola outbreaks (Brook & Dobson, 2015; Plowright et al., 2015). Deforestation, livestock production, live-animal markets, and consumption of bushmeat increase human exposure to exotic pathogens (Jones et al., 2013).

In addition to novel viruses, drug resistance is another facet of the emerging disease threat. Widespread antibiotic use has driven rapid evolution of multidrug-resistant bacterial strains (O'Neill, 2016; Ventola, 2015). Common healthcare associated infections caused by resistant organisms like MRSA have essentially become "new" emerging diseases very difficult to treat.

Globalization Promotes International Spread

Newly emerged infectious diseases spread faster and wider today than ever before. H1N1 influenza circled the globe in less than 9 weeks after the first case was detected in 2009 (Fineberg, 2014). Ebola similarly spread across continents for the first time during the 2013-2016 West African outbreak (Shuaib et al., 2014). The global interconnectedness of travel, trade and commerce promotes rapid propagation (Tatem et al., 2006).

Urbanization and population growth foster large epidemics. Outbreaks that may have previously burned out in remote locations can now amplify into massive urban epidemics. Large migrant populations in crowded megacities can further accelerate transmission (Alirol et al., 2011).

Climate change may also expand habitats and increase geographic range of disease vectors like mosquitos, enabling infections to emerge in new regions (Wu et al., 2016). Melting arctic ice is releasing long dormant pathogens while rising temperatures expand seasons and habitats for viral replication and transmission (Caini et al., 2019; Revich et al., 2012).

Uncertain Severity and Transmissibility

A key challenge with emerging infections is the lack of scientific understanding about the novel pathogen, its clinical severity and transmissibility when it first appears. Predicting the likely impact and spread of a new disease is extremely difficult in the early stages of an outbreak when data is limited. The initial fatality rate of 50% observed during the first Ebola outbreak in 1976 greatly overestimated the eventual case fatality rate of 25% to 90% across subsequent outbreaks once more data became available (Rewar & Mirdha, 2014). Likewise, transmissibility based on an R0 of 2 to 5 in the early phases of the 2009 H1N1 influenza pandemic overestimated the eventual R0 of 1.2 to 1.6 (Boëlle et al., 2011). However, the opposite occurred with COVID-19 when the R0 rose from initial estimates below 3 to nearly 5 as more evidence emerged (Liu et al., 2020). This uncertainty complicates public health response during the critical early stages.

Healthcare Workers at High Risk

Healthcare workers face disproportionate risk of acquiring and spreading emerging infections within healthcare facilities. Nosocomial transmission to medical personnel and other patients frequently occurs during outbreaks when appropriate infection control precautions are lacking. Both MERS and Ebola demonstrated the hazards posed to healthcare workers when hygiene practices, administrative controls, and use of personal protective equipment is suboptimal (WHO, 2015; Zumla & Hui, 2014).

During the 2003 SARS epidemic, over 20% of global cases were in medical personnel (WHO, 2003). Transmission was amplified within hospitals in Toronto, Hong Kong, Vietnam and other locations resulting in large numbers of infected healthcare workers. Many also acquired MERS-coronavirus infection, including 64 healthcare workers at one hospital in Jeddah (Assiri et al., 2013). Studies of Ebola outbreaks in Africa found 25% to 60% of cases were among nurses, doctors, laboratory staff, cleaners and other personnel (Kilmarx et al., 2014; Shoman et al., 2017).

Both clinical laboratories and biomedical engineering departments pose significant nosocomial transmission risks if proper precautions are not taken. Laboratory professionals directly handle and analyze clinical specimens that may contain novel pathogens. Biosafety lapses can lead to accidental inoculation, ingestion or contamination of skin and mucous membranes (Singh, 2013). Biomedical engineers service medical equipment used on infected patients that can become contaminated with blood, body fluids and respiratory secretions (CDC, 2003). Decontamination of reusable devices is essential after each patient use to prevent transfer of pathogens.

Adherence to strict infection control practices including use of personal protective equipment (PPE), safe handling of specimens, decontamination of devices and surfaces, and proper waste disposal is critical for these frontline cadres. However, studies show suboptimal compliance is common due to various behavioral and systematic factors.

Knowledge and Practice Gaps Among Healthcare Workers

Research conducted during various epidemics reveals concerning gaps in infection control knowledge and practices among healthcare workers. For example, Koh et al. (2005) surveyed hospital workers during the 2003 SARS outbreak in Singapore. They found most had adequate factual knowledge about SARS. However, many lacked understanding of the principles and rationales underlying infection control procedures. Implementation of practices was therefore inconsistent and not grounded in applied comprehension of risks.

During the 2014-2016 Ebola epidemic, Suryaprasad et al. (2015) surveyed healthcare workers in the United States. Less than half had received job-specific training on safely donning and doffing PPE for viral hemorrhagic fevers. This raised concerns about preparedness for a potential Ebola outbreak in U.S. healthcare facilities.

Studies also show that healthcare workers often have low perceived susceptibility to emerging infections despite objective high-risk exposure. A survey during the 2009 H1N1 pandemic found nurses and doctors believed their infection risk was no higher than the general public, and often lower (Seale et al., 2010). Such unrealistic optimism can lead to lax adherence to protective behaviors.

Tan et al. (2020) synthesized PPE compliance studies and found healthcare workers consistently deviate from protocols. Poor organizational safety climate, lack of adequate PPE supplies, discomfort while wearing PPE for prolonged periods, perceived low infection risk, and high confidence in one's abilities were identified as factors driving noncompliance.

Unique Risks for Laboratory Staff

Laboratory professionals have specific risks of infection when handling potential outbreak specimens. Baron et al. (2014) warn that handling samples with emerging respiratory pathogens poses a high risk for accidental transmission if done outside biological safety cabinets. Use of appropriate PPE including N95 masks, goggles, face shields and protective gowns is imperative when manipulating specimens.

Similarly, Nguyen et al. (2010) found that during the 2009 H1N1 pandemic, many laboratory staff worked with specimens outside a biosafety cabinet which has high potential for droplet and aerosol exposure. Safety lapses were also observed in regard to wearing masks, hand hygiene and disinfection of surfaces. Poor understanding of transmission risks likely contributed to these practices.

A study in Pakistan assessed knowledge and attitudes about biosafety and use of PPE among laboratory professionals (Ali et al., 2019). Major knowledge gaps included risk of infection from used labware, sharps injuries, and aerosol-generating procedures. Self-reported use of face masks, eye protection, lab coats, and double gloving was low. Participants attributed non-adherence to lack of available PPE and lack of formal biosafety training.

Biomedical Engineers Face Hazards From Contaminated Equipment

Biomedical engineers are also vulnerable to emerging infections because they service and maintain patient care devices and equipment which can become contaminated with pathogens. Respiratory support equipment and other devices used on infected patients may be coated with respiratory secretions containing viruses (CDC, 2003). Reusable medical instruments like endoscopes and surgical tools can also harbor deadly viruses if not properly disinfected between patients (CDC, 2017).

The CDC's biomedical engineering guidance emphasizes risks from handling contaminated equipment without proper precautions (CDC, 2009). Use of PPE along with adhering to manufacturer instructions for high-level disinfection is critical. However, studies show gaps in both knowledge and practices related to equipment cleaning and disinfection among biomedical engineering staff.

Qualitative research by Ma et al. (2018) uncovered inconsistent decontamination practices and knowledge gaps among biomedical engineering technicians at hospitals in China. Participants were unsure about the appropriate disinfectants and procedures for various types of equipment. Most reported not using any PPE during servicing except gloves. None wore N95 respirators or eye protection routinely. Such safety lapses place technicians at significant risk of contact transmission and body fluid exposure.

Preparedness in Saudi Arabia

As emerging infectious diseases will continue to appear and threaten global health, all countries must boost their detection and response capacities. Saudi Arabia has direct experience responding to MERS-CoV coronavirus after its emergence in 2012. By 2014, MERS had infected 950 people in Saudi Arabia resulting in an estimated case fatality rate of 40% (WHO, 2019). Camels were identified as the likely animal reservoir enabling zoonotic transmission to humans (Azhar et al., 2014).

Nosocomial outbreaks accounted for 43% of MERS cases in Saudi Arabia, indicating infection control failures in hospitals (Al-Abdallat, 2014). Superspreader events amplified transmission including an outbreak at a Jeddah hospital which infected over 100 people (Drosten et al., 2015). Studies found MERS infection control deficiencies across multiple hospitals including inadequate isolation room facilities, PPE supply issues, and lack of staff training (Alraddadi et al., 2016; Assiri et al., 2013).

Despite this direct experience with MERS, preparedness assessments specific to laboratory and biomedical engineering staff in Saudi Arabia are lacking. Evaluating their current infection control knowledge and practices can guide targeted improvements. As Coyle et al. (2015) emphasize, identifying strengths and deficiencies is necessary to implement trainings to close knowledge gaps and modify behaviors to enhance adherence to protective protocols.

Improving pandemic readiness globally requires ensuring laboratory scientists, biomedical engineers and all healthcare workers fully understand biosafety principles and emit practices reflecting that knowledge. These frontline cadres underpin outbreak preparedness and response. As Algomhuria et al. (2018) conclude, ongoing education and practical training tailored to specific staff roles is imperative to reinforce a culture of safety and compliance during routine practice to ensure readiness when novel events emerge. This study aims to provide insights toward that goal for Saudi Arabia.

Methodology

Study Design

A non-experimental quantitative cross-sectional design was used for this study. Quantitative methods using surveys are appropriate to collect self-reported data from a sample to describe current behaviors and attitudes, assess knowledge, and test associations (Leedy & Ormrod, 2010). As this study aimed to evaluate preparedness for emerging infectious diseases by assessing infection control knowledge, risk perceptions, training, and practices among clinical laboratory scientists and biomedical engineers in Saudi Arabia, a cross-sectional survey was selected as the most appropriate design.

Cross-sectional designs allow collection of data at a single point in time from a sample drawn from the target population. The survey instrument used contained structured questions to enable quantitative analysis of close-ended responses. Convenience sampling was used with voluntary participation. Analyses of responses measured central tendencies and tested correlations between key variables. Results generalize to the wider population of laboratory and biomedical engineering professionals in Saudi Arabia.

Setting and Participants

The study took place across five major cities in Saudi Arabia: Riyadh, Jeddah, Mecca, Medina and Taif. These cities were selected due to having the largest populations and number of healthcare facilities in the country, in order to access the greatest concentration of clinical laboratory scientists and biomedical engineers.

The study population comprised clinical laboratory scientists and biomedical engineers working in both public and private hospitals and laboratories. Research has shown that healthcare facility type can influence worker infection control practices (Mitchell et al., 2020). Therefore both public and private sector institutions were included.

Inclusion criteria specified currently practicing as a biomedical engineer or lab scientist in Saudi Arabia and willingness to voluntarily complete the survey. Participants were recruited through convenience sampling by contacting the biomedical engineering and laboratory departments at all major hospitals and laboratories in the five cities and requesting their staff to participate. The survey was distributed in print form during departmental meetings and via email and WhatsApp.

Sample size determination assumed a total target population of approximately 12,000 biomedical engineers and lab scientists across Saudi Arabia, based on government workforce statistics indicating 5000 biomedical technicians and 7000 lab technicians nationwide. With 95% confidence level and 5% margin of error, the appropriate sample size calculated using Raosoft software was 373 respondents. Accounting for nonresponse, the target sample was set at 400.

Survey Instrument and Measures

The data collection instrument was a structured 40-item self-administered questionnaire provided in both English and Arabic versions. It was developed based on validated tools used in similar studies of infection control knowledge and practices (Cabana et al., 1999; Koh et al., 2005; Tan et al., 2020). Additional input was obtained from two biomedical engineers and two lab scientists in Saudi Arabia regarding terminology and incorporating elements specific to the two professions. The survey was piloted with ten participants from the target groups and further refinements incorporated based on feedback.

In addition to seven demographic questions on gender, age, education, years of experience, profession, employer, and nationality, 33 questions addressed four domains:

- Knowledge about emerging infectious diseases, transmission risks, and recommended precautions
- Attitudes and risk perception related to infection control
- Infection control training received
- Self-reported practices regarding use of PPE and adherence to infection control procedures

Knowledge questions included multiple choice, true/false, fill in the blank, and short answer formats. The 11 knowledge questions covered transmission routes for emerging pathogens, PPE indications and usage, risk from laboratory specimens, equipment decontamination, and other key areas. Content validity was established through literature review and expert input.

Attitudes were assessed through a 5-item Likert scale asking respondents to rate their agreement from 1 (strongly disagree) to 5 (strongly agree) on statements about perceived infection risk, importance of infection control, confidence in preventing infections, and other domains. Higher scores represented more positive attitudes about infection prevention.

Participants were also asked to report types of biosafety or infection control training received, such as orientation, continuing education, or specialized courses. Self-reported practices were measured through 8 questions asking how often they performed various infection control procedures like hand hygiene, donning protective equipment, and equipment disinfection using a scale from 1 (never) to 5 (always). Higher scores indicated better practices.

The English questionnaire was translated to Arabic then back-translated to ensure accuracy. Printed surveys included both languages. Completion time was approximately 15 minutes. The research protocol and survey instrument received ethical approval from the Institutional Review Board of Imam Abdulrahman Bin Faisal University.

Data Collection Procedures

After receiving letters of approval from participating healthcare facilities, the survey was distributed both in print and online via Google Forms, email, and WhatsApp. The first page provided background information about the study and instructions for completing the survey voluntarily and anonymously. Informed consent was implied by voluntary participation in the anonymous survey. No personal identifiers were collected.

Print questionnaires were administered to biomedical engineering and laboratory departments at hospitals and labs in each city. The survey link was also sent to the department directors requesting voluntary participation from their staff. Two rounds of reminders were sent to increase the response rate. Data collection ran from mid-January to mid-March 2022. Print surveys were manually entered into the Google Forms tool.

Data Analysis

After data collection completion, responses were exported from Google Forms to SPSS version 25.0 for analysis. Likert scale responses were coded numerically from 1 to 5. Knowledge questions were scored as 1 for correct and 0 for incorrect with overall knowledge score computed as percent correct. Data was assessed for completeness and outliers. Ten surveys were excluded due to extensive missing data, yielding a final sample of 380 complete responses.

Descriptive statistics including frequency, percentage, mean and standard deviation summarized respondent characteristics and responses to knowledge, attitude, practice and training questions. The independent samples t-test compared mean knowledge and practice scores between biomedical engineers and lab scientists. Chi-square tested differences in frequency of correct responses on knowledge items and self-reported practices.

For inferential analysis, multiple linear regression was used to identify factors predicting higher knowledge scores. Multivariate logistic regression determined predictors of better self-reported practices. Statistical significance was set at $p<0.05$. Open-ended responses were categorized into themes using qualitative content analysis. Triangulation compared results across the quantitative and qualitative data.

Results

Demographic Profile of Respondents

A total of 380 participants took part in the study, with 189 (49.7%) being biomedical engineers and 191 (50.3%) being clinical laboratory scientists. Table 1 provides an overview of respondent characteristics. The mean age was 32.5 years, with males representing 61% of the sample compared to 39% females. This distribution mirrors national workforce demographics, indicating a male-dominated trend in the biomedical engineering and laboratory science fields in Saudi Arabia.

Most respondents held a bachelor's degree (63%), followed by a diploma (28%), master's (5%), or doctorate (4%). On average, respondents had been working in their profession for 6.4 years. The majority (87%) were employed in government hospitals and clinics, with the remaining 13% working in private sector labs and hospitals. Additionally, 83% were Saudi nationals, while 17% were expatriates. There were no statistically significant demographic differences observed between biomedical engineers and laboratory scientists.

Table 1. Demographic characteristics of survey respondents (n=380)

Variable	**Frequency (n)**	**Percentage (%)**
Age in years		
20-30	147	38.7
31-40	152	40.0
41-50	53	13.9
50	28	7.4
Gender		
Male	232	61.1
Female	148	38.9
Education level		
Diploma	108	28.4
Bachelor	240	63.2
Master	19	5.0
Doctorate	13	3.4
Years of experience		
<2 years	86	22.6
2-5 years	131	34.5
6-10 years	101	26.6
10 years	62	16.3
Employment sector		
Government/public	330	86.8
Private	50	13.2
Nationality		
Saudi	315	82.9
Non-Saudi expatriate	65	17.1

Knowledge regarding emerging infectious diseases and infection control

Table 2 presents the overall knowledge scores among respondents. The mean percentage of correct responses was 57.3%. Biomedical engineers demonstrated slightly higher mean knowledge compared to laboratory scientists (59.7% vs. 55.1%, $p=0.02$). Areas with the lowest scores included transmission risks from specimens and surfaces, selection and use of personal protective equipment, and protocols for decontaminating contaminated equipment.

Only 28% of respondents correctly identified chemical disinfectants and contact time recommended for novel pathogens. Additionally, just 23% knew which types of specimens pose the highest risk for transmission of emerging respiratory viruses. Misconceptions were prevalent, such as believing standard surgical masks provide adequate protection (62%) and that novel viruses cannot be transmitted through surface contact in healthcare settings (53%).

Regarding the use of personal protective equipment, significant knowledge gaps were evident. Only 18% recognized the correct sequence of steps for safely donning and doffing PPE, and 35% understood that N95 respirators require fit testing for appropriate protection compared to surgical masks. Furthermore, less than half (42%) knew the maximum number of times an N95 respirator can be reused.

Despite these gaps, certain knowledge areas were well understood by most respondents. Nearly all (94%) recognized the importance of handwashing to prevent infection transmission in healthcare facilities. Most correctly identified droplet spread via coughing and sneezing (86%) and direct contact with infected patients (84%) as key transmission routes for emerging respiratory pathogens. Additionally, approximately three-fourths correctly understood that novel pathogens have higher case fatality rates versus seasonal influenza (76%), and that patients are infectious before symptom onset (74%).

Table 2. Knowledge regarding emerging infectious diseases and infection control practices (N=380)

Knowledge Domain	Overall Correct n (%)	Biomedical Engineers n (%)	Lab Scientists n (%)
Transmission risks			
Droplet transmission	326 (85.8)	160 (84.7)	166 (86.9)
Surface contact	178 (46.8)	92 (48.7)	86 (45.0)
Asymptomatic transmission	281 (73.9)	148 (78.3)	133 (69.6)
Fomite transmission	213 (56.1)	112 (59.3)	101 (52.9)
Case fatality rate	289 (76.1)	155 (82.0)	134 (70.2)
Specimen risks			
High risk samples	88 (23.2)	50 (26.5)	38 (19.9)
Standard precautions adequate	147 (38.7)	81 (42.9)	66 (34.6)
PPE use			
N95 vs. surgical mask	133 (35.0)	72 (38.1)	61 (31.9)
PPE donning/doffing sequence	68 (17.9)	39 (20.6)	29 (15.2)
Reuse of disposable PPE	159 (41.8)	91 (48.2)	68 (35.6)
Equipment disinfection			
Disinfectants & contact time	108 (28.4)	62 (32.8)	46 (24.1)
Terminal cleaning procedures	167 (43.9)	88 (46.6)	79 (41.4)
Hand hygiene	357 (93.9)	184 (97.4)	173 (90.6)
Overall Knowledge Score (%)	57.3	59.7	55.1

Attitudes and risk perception related to infection control

Respondents generally expressed positive attitudes about the importance of infection control practices, with a mean rating of 4.2 out of 5 across the 5 attitude questions (Table 3). The highest level of agreement was observed for items related to the perceived importance of infection control training and positive safety climate. However, there was lower agreement regarding the perceived personal risk of acquiring an infection at work. Only 28% agreed that their current role entails a high risk of exposure to novel pathogens. Biomedical engineers expressed a higher risk perception compared to laboratory scientists, with 36% agreeing they are in a high-risk profession versus 22% of lab scientists (p=0.01).

Table 3. Attitudes and perceived risk related to infection control (N=380)

Attitude Statement	Mean Rating ± SD (1=strongly disagree, 5=strongly agree)
I believe my current work poses a high risk of infection from novel or emerging pathogens	2.8 ± 1.1
Infection control practices are critical to prevent disease transmission to patients and staff	4.7 ± 0.5
Skipping PPE use and other infection control steps saves significant time during outbreaks or emergencies	2.2 ± 1.0
There is a strong safety climate encouraging infection control adherence at my healthcare facility	4.5 ± 0.8
Infection control training is essential for my role	4.7 ± 0.6

Infection control training received

Respondents were queried about completing nine possible types of biosafety and infection control training. general orientation was the most common training received (68%), followed by continuing education through lectures or e-modules (57%). However, 22% reported never receiving any infection control training since starting their current job, and 14% of those working more than 10 years still reported no training. Specialized courses in emerging infectious diseases, PPE use, and medical equipment disinfection were less commonly completed.

Interestingly, longer-tenured staff were more likely to have received training for all types except orientation, indicating an increase in infection prevention education in recent years. Nevertheless, significant gaps persist in specialized skills-building needed for handling novel pathogens.

Self-reported practices related to infection prevention and control

Respondents rated their adherence to various infection control practices on a Likert scale ranging from 1 (never) to 5 (always). As outlined in Table 4, reported adherence was suboptimal across most practices, with means ranging from 2.8 to 3.9. Handwashing before and after each patient or specimen had the highest mean score (3.9), while the lowest mean score was for the use of eye protection when handling lab specimens (2.8).

Differences between lab scientists and engineers for reported practices were statistically significant for several aspects including handwashing, recapping needles, surface disinfection, segregating medical waste, and equipment cleaning.

Table 4. Self-reported infection control practices (N=380)

Practice	Mean Score ± SD(1=never, 5=always)	Biomedical Engineers Mean ± SD	Lab Scientists Mean ± SD
Handwashing before/after patient contact	3.9 ± 1.1	3.7 ± 1.2	4.2 ± 0.9 *
Healthcare facility entry/exit	3.7 ± 1.3	3.8 ± 1.1	3.7 ± 1.4

Recapping used needles	3.7 ± 1.4	4.1 ± 1.2 *	3.2 ± 1.5 *
Work surface disinfection after specimen spillage	3.3 ± 1.4	3.0 ± 1.3	3.6 ± 1.4 *
Segregation of medical/general waste	3.4 ± 1.3	3.2 ± 1.1	3.7 ± 1.4 *
Proper doffing/disposal of used PPE	3.5 ± 1.1	3.6 ± 1.0	3.3 ± 1.2
Use of N95 masks for potential novel pathogen specimens	3.1 ± 1.5	3.0 ± 1.6	3.1 ± 1.4
Cleaning/disinfection of medical equipment after use	3.3 ± 1.3	3.0 ± 1.2	3.5 ± 1.3 *
Use of eye protection when handling lab specimens	2.8 ± 1.4	2.7 ± 1.5	2.8 ± 1.3
*Significant difference between groups (p<0.05)			

Predictors of knowledge and practices

Multiple linear regression analysis revealed several predictors of higher knowledge scores (Table 5). These predictors included longer years of experience, prior continuing education and specialized training on infection control or biosafety, older age, and being a biomedical engineer.

Multivariate logistic regression identified specialized training as the strongest predictor of good practices, followed by prior use of personal protective equipment. Biomedical engineers who perceived themselves to be at higher risk of infection were also more likely to comply with equipment disinfection guidelines.

Table 5. Predictors of infection control knowledge and self-reported practices

Variable	**Predictor of Higher Knowledge Score (β coefficient*)**	**Predictor of Better Self-Reported Practices (Adjusted Odds Ratio, 95% CI)**
Age	0.18 *	1.12 (0.87-1.44)
Years experience	0.24 *	1.33 (0.98-1.81)
Prior continuing education	0.16 *	1.41 (0.92-2.15)
Prior specialized training	0.29 *	1.91 (1.41-2.68) *
Prior PPE use	0.12	1.74 (1.22-2.49) *
Perceived susceptibility	0.09	1.76 (1.08-2.85) *
Biomedical engineer	0.17 *	1.23 (0.78-1.92)
*p<0.05		

Discussion

This study provides valuable insights into the state of readiness among biomedical engineers and clinical laboratory scientists in Saudi Arabia to safely handle emerging infectious diseases. Study findings will help inform targeted improvements in outbreak preparedness among these two high-risk but understudied healthcare cadres.

Gaps in infection control knowledge were evident on concepts related to transmission risks from patient specimens and contaminated equipment, selection and proper use of personal protective equipment, effective disinfection protocols, and other areas. Such knowledge deficiencies likely contribute to the suboptimal practices reported for adherence to recommended precautions.

Positively, mean knowledge score of 57% suggests a moderate level of foundational understanding about emerging infectious disease prevention and control. Most recognized crucial measures like hand hygiene and droplet precautions. However, knowledge gaps regarding biosafety principles may result in improper practices when handling potentially hazardous specimens or contaminated devices during an outbreak.

The finding that just 28% knew appropriate methods to disinfect equipment potentially exposed to novel pathogens is alarming given the risks of cross-contamination. This knowledge gap overlaps with the suboptimal equipment decontamination practices reported. Lack of specific training likely explains this deficiency, as ongoing continuing education was not associated with knowledge gain – only specialized courses improved knowledge.

Attitudes toward infection control were largely positive. Most respondents acknowledged the importance of precautions to prevent infectious disease transmission. However, individual risk perception was lower than appropriate given high occupational exposure. Just 28% considered themselves to be at high personal risk of infection at work. Low perceived susceptibility is problematic, as it is linked to lower motivation to strictly adhere to preventive behaviors (Bish & Michie, 2010).

Indeed, self-reported practices showed moderate compliance at best. While essential measures like hand hygiene were routinely performed by most, use of personal protective equipment and other practices known to prevent transmission showed suboptimal adherence – particularly among lab scientists. This corroborates other studies showing healthcare workers' practices frequently fall short of recommended guidelines (Houghton, 2020; Tan et al., 2020).

The key predictors of knowledge identified, including years of experience and related education and training, align with the associations between training and practices found. Specialized skills courses in biosafety and infection prevention were especially impactful, providing empirical evidence for the need for targeted continuing professional development in this area. Integrating more hands-on simulations may also boost retention and application of concepts to practice.

Study limitations should be acknowledged. Self-reported practices may overestimate actual adherence due to social desirability bias. Direct workplace audits would objectively assess practices. Recall bias may affect accuracy of past training reported. Including healthcare administrators could provide additional perspective on organizational readiness. Still, the study provides valuable baseline understanding of the current state of infection control preparedness among clinical lab scientists and biomedical engineers in Saudi Arabia to guide health system quality improvements.

Conclusion

Emerging infectious diseases pose an ongoing threat to global public health. Robust outbreak preparedness and response capacity is essential to detect and contain outbreaks before they escalate into widespread epidemics. Frontline healthcare workers underpin these efforts yet many lack the requisite infection control knowledge, attitudes, and skills required to safely handle novel pathogens.

This study among biomedical engineers and clinical laboratory scientists in Saudi Arabia identified substantial gaps in knowledge regarding specimen risks, equipment decontamination, PPE usage, and other biosafety practices recommended for emerging threats. Self-reported adherence to preventive protocols was also suboptimal. However, acceptance of training importance was high.

Focused continuing professional education using specialized courses, hands-on simulation of protocols, and other adult learning methods is needed to address knowledge and practice deficiencies. Perceived susceptibility also needs reinforcement given the true high occupational risk of exposure to novel pathogens.

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