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Laboratory Focus on Improving the Culture of Biosafety: Statewide Risk Assessment of Clinical Laboratories That Process Specimens for Microbiologic Analysis

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ABSTRACT The Wisconsin State Laboratory of Hygiene challenged Wisconsin laboratories to examine their biosafety practices and improve their culture of biosafety. One hundred three clinical and public health laboratories completed a questionnaire-based, microbiology-focused biosafety risk assessment. Greater than 96% of the respondents performed activities related to specimen processing, direct microscopic examination, and rapid nonmolecular testing, while approximately 60% performed culture interpretation. Although they are important to the assessment of risk, data specific to patient occupation, symptoms, and travel history were often unavailable to the laboratory and, therefore, less contributory to a microbiology-focused biosafety risk assessment than information on the specimen source and test requisition. Over 88% of the respondents complied with more than three-quarters of the mitigation control measures listed in the survey. Facility assessment revealed that subsets of laboratories that claim biosafety level 1, 2, or 3 status did not possess all of the biosafety elements considered minimally standard for their respective classifications. Many laboratories reported being able to quickly correct the minor deficiencies identified. Task assessment identified deficiencies that trended higher within the general (not microbiology-specific) laboratory for core activities, such as packaging and shipping, direct microscopic examination, and culture modalities solely involving screens for organism growth. For traditional microbiology departments, opportunities for improvement in the cultivation and management of highly infectious agents, such as acid-fast bacilli and systemic fungi, were revealed. These results derived from a survey of a large cohort of small- and large-scale laboratories suggest the necessity for continued microbiology-based understanding of biosafety practices, vigilance toward biosafety, and enforcement of biosafety practices throughout the laboratory setting.

KEYWORDS laboratory biosafety, laboratory-acquired infections, risk assessment

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Clinical, public health, and research laboratories must constantly demonstrate vigilance in the context of hazards associated with the cultivation and propagation of infectious agents. The scope of laboratory-acquired infections was the subject of a recent review by Singh (1). On an historic basis, the most commonly reported laboratory-associated infections included brucellosis, Q fever, hepatitis, typhoid fever, tularemia, tuberculosis, dermatomycosis, Venezuelan equine encephalitis, psittacosis, and coccidioidomycosis (2, 3), with case fatality rates ranging from <0.5% (Q fever, dermatomycosis) to >7.5% (typhoid fever, psittacosis) (4). Contemporary surveys have revealed that tuberculosis, brucellosis, and enteric infections (particularly shigellosis) are among the most common laboratory-acquired infections (5, 6). Noteworthy for *Brucella* spp. is an occupational infection risk (641 cases per 100,000 microbiologists) that substantially exceeds that for the general population (0.08 cases per 100,000 individuals) (6). A similar disparity has been noted for *Neisseria meningitidis*. Moreover, one cannot discount the impact of additional laboratory-acquired fungal (7–9), viral (7, 10–12), and parasitic (13, 14) agents of infection, as well as purported bioweapons (15), on the landscape of biosafety.

In a regional U.S. survey conducted from 1978 to 1982, Jacobson et al. (16) reported an annual laboratory-acquired infection incidence rate of 5.0 per 1,000 laboratorians within small laboratories (defined as ≤25 laboratorians), which is in contrast to a rate of 1.5 per 1,000 laboratorians in larger laboratories ($P < 0.05$). On the other hand, a survey of doctoral-level clinical microbiology directors (6) revealed that laboratories serving clinical entities with >200 beds reported more instances of exposure and infections over a 3-year period than did perceived smaller laboratories. In this data set, the greater proportion of laboratory-acquired infections caused by *Shigella* spp., *Brucella* spp., *Salmonella* spp., *Staphylococcus aureus*, *Escherichia coli* O157:H7, and *Coccidioides immitis* emanated from the larger laboratories. These variable data imply that all laboratory professionals be trained to safely assess the risk of the tasks that they perform.

Laboratory biosafety is a form of prospective risk management in which individuals make judgments to avoid potentially negative outcomes while being cognizant of the fact that the information provided may contain uncertainty. In this dynamic paradigm, successful risk management and the prevention of laboratory-acquired infections may be impacted by sample volume, microbial pathogenicity, routes of exposure, host immune status, and the workload, knowledge, and experience of the individuals in the laboratory (17). A formal biosafety risk assessment is a three-facet process by which hazards are identified, the risk associated with these hazards is evaluated, and the means by which the hazard can be eliminated or controlled are determined (18).

The Wisconsin Clinical Laboratory Network (WCLN) is a clinical and public health laboratory network developed by the Wisconsin State Laboratory of Hygiene (WSLH). A subgroup of this network is a Laboratory Technical Advisory Group (LabTAG) that assists WSLH in training, educational, and collaborative activities (19). With the overall goal of improving the culture of biosafety in Wisconsin laboratories, LabTAG developed a tool that was distributed to WCLN laboratories for the self-performance of a microbiology-focused biosafety risk assessment. The survey nature of this tool facilitated a baseline assessment of a large cohort of clinical and public health laboratories in the performance of microbiology duties ranging from specimen triage to full culture analysis.

MATERIALS AND METHODS

A questionnaire for biosafety risk assessment was collaboratively developed by WSLH and LabTAG and distributed to 150 WCLN laboratories in the fall of 2015. This questionnaire was divided into two sections. The initial portion of the questionnaire was a facility assessment (assessment of risk on the basis of the laboratory structure and design), in which laboratories were asked to report their biosafety level (BSL) status in the context of itemized standards published by U.S. federal agencies (20). The second portion of the questionnaire was a task assessment (assessment of risk on the basis of the tasks/tests performed in the laboratory) in which laboratories were requested to scrutinize their risk relative to seven core activities: specimen collection and transport; specimen processing and handling; rapid nonmolecular, nonserology assays (examples range from rapid influenza virus antigen detection to HIV antibody

detection using membrane-bound cartridges); direct microscopic examination (including parasitology); culture setup; performance of screening cultures (either those that involve chromogenic media or those in which negative plates are discarded and positive plates are shipped to a reference laboratory); and culture interpretation (including interpretation of routine bacteriology, mycology, mycobacteriology, and virology cultures). Queries related to task assessment encompassed the preanalytic, analytic, and postanalytic stages for each core activity. The respondents were asked to indicate their utilization of required and additional preferred mitigation control measures, as described by the risk assessment document. Required mitigation controls were those compiled from a number of sources (20–22), while additional preferred mitigation controls were largely reflective of best practices. Questions were written in a fashion to prompt a yes/no response. Responses of "no" were classified as biosafety gaps, and the laboratories were asked to provide commentary on responses of "no."

RESULTS

Scope of activity. By early 2016, 103 of 150 laboratories (68.7%) had returned completed surveys. While all respondents acknowledged participation in at least one core microbiology activity, the scope of service was variable throughout the WCLN. Of all the respondents, ≥96.1% performed activities related to four core activities: specimen collection and transport; specimen processing and handling; rapid nonmolecular, nonserology assays; and direct microscopic examination (Table 1). A total of 90.3% of the laboratories engaged in the primary processing of routine bacterial, fungus, acid-fast bacillus (AFB), and/or virus cultures. In contrast, 55.3% and 59.2% of the respondents were involved in screening and increased-complexity culture interpretation, respectively (Table 1). When assessing laboratory risk in a general sense, the respondents were more likely to cite specimen source and the specific clinical test requisition (e.g., AFB culture, fungus culture) than considerations such as patient occupation, patient travel history, and the health status of the individuals performing the testing (Table 2).

Facility assessment. According to the 5th edition of *Biosafety in Microbiological and Biomedical Laboratories* (20), 15 minimal criteria must be met for a laboratory to receive a BSL-1 classification. Of the 103 survey respondents, the vast majority reported compliance with nine of these criteria, with nearly 90% of the respondents having a laboratory design compatible with cleaning and possession of a hand-washing sink near the laboratory exit (Table 3). Criteria for BSL-1 status with which the laboratories had lower rates of compliance included implementation of an effective pest management program (82.5% of the respondents); decontamination of cultures, stocks, and other infectious materials prior to disposal (76.7%); the presence of screen-fitted exterior windows (69.9%); and placement of a biohazard sign at the entrance of the laboratory when infectious agents are present (61.2%). With respect to signage content, significant deficits were additionally noted (and easily corrected) and included the provision of the laboratory biosafety level, the name of the supervisor or some other contact, the telephone number for the contact, and the procedure required for entering/exiting the laboratory.

Beyond the aforementioned criteria required for BSL-1 status, 14 additional minimal criteria must be satisfied for BSL-2 classification (20). Of the 84 respondents claiming BSL-2 status, the vast majority demonstrated compliance with eight of these elements. Almost 90% of the respondents reported the presence of self-closing doors that may be locked to control access to the laboratory (Table 4). The percentage of laboratories that decontaminate (by autoclave, incineration, or chemical treatment) potentially infectious laboratory waste prior to disposal and that advise persons entering the laboratory of the potential presence of hazards was nearly the same for each of these two criteria. Data showing that less than three-fourths of the respondents open centrifuge safety cups/carriers in a biosafety cabinet, possess an automatic or manually operated hands-free hand-washing sink, and maintain vacuum lines with HEPA filters suggest that additional mitigation steps during these processes would improve biosafety practices even further, ultimately improving the culture of biosafety.

Nine laboratories self-reported that they were at BSL-3 status, yet no single laboratory satisfied all 12 additional minimal criteria for that designation (data not illustrated). Specific opportunities for improvement were both operational (annual testing and/or

TABLE 1 Scope of microbiology-related activities among WCLN risk assessment survey respondents, 2016[a]

Activity	% of respondents
Specimen collection and transport	
Phlebotomy	95.1
Specimen transport	93.2
Assist with collection of bone marrow aspirate specimens	58.3
Collection of nasal swab specimens	54.4
Collection of throat swab specimens	50.5
Assist with collection of fine-needle aspirate specimens	37.8
No engagement in specimen collection and transport	2.9
Specimen processing and handling	
Specimen handling	97.1
Utilization of biosafety cabinet	94.2
Specimen receipt	94.2
Packaging and shipping of primary specimens	79.6
Utilization of chemical fume hood	46.6
No engagement in specimen processing and handling	1.0
Performance of rapid nonmolecular, nonserology assays for:	
Legionella pneumophila	98.1
Streptococcus pyogenes	86.4
Respiratory syncytial virus	71.8
Influenza virus	69.9
Cryptosporidium spp./*Giardia* spp.	35.0
Shiga toxin	25.2
Clostridium difficile	25.2
Rotavirus	24.3
Streptococcus pneumoniae	22.3
Other agents	[b]
No engagement in rapid nonmolecular, nonserology assays	3.9
Direct microscopic examination by:	
Gram staining	88.3
Cell count and differential	88.3
Wet mount microscopy	88.3
Urinalysis	87.4
KOH/calcofluor white staining	73.8
AFB staining	20.4
Parasitology	17.5
Virus immunofluorescence	2.9
No engagement in direct microscopic examination	3.9
Culture setup for:	
Blood culture	81.6
Routine bacteria	76.7
Fungus	30.1
AFB	23.3
Virus	2.9
No engagement in culture setup	9.7
Screening cultures[c]	
Throat swab specimens	45.6
Methicillin-resistant *Staphylococcus aureus*	42.7
Urine specimens	38.8
Other[d]	31.1
No engagement in screening cultures	44.7
Culture interpretation	
Routine bacteriology	59.2
Fungus	21.4
AFB	16.5
Virus	2.9
No engagement in culture interpretation	40.8

(Continued on next page)

TABLE 2 Routine considerations when assessing laboratory risk, WCLN risk assessment survey respondents, 2016[a]

Consideration	% of respondents
Specimen source and associated pathogens	100.0
Test requisition[b]	98.1
Method of transmission and infectious dose	84.5
Risk factors for persons performing testing[c]	81.6
Patient symptoms and travel history	51.5
Patient occupation	24.3

[a]Data are for 103 respondents.
[b]Including, but not limited to, tests for systemic mycotic agents, acid-fast bacilli, viruses, and potential bioterrorism agents.
[c]Including, but not limited to, immunization status, pregnancy, illness or treatment, physical disability, and training and experience.

replacement of HEPA filters) and administrative (verification and documentation of parameters and procedures both prior to facility opening and on an annual basis) in nature. Opportunities for improvements in design were also evident and related to requirements for impervious, slip-resistant flooring; proper sealing of doors, ventilation openings, walls, and ceilings; nonreversal of airflow in the event of failure conditions; and HEPA filtering of laboratory exhaust.

Task assessment. Of all the respondents, ≥88% complied with 93 of the 121 required mitigation control measures within the task assessment. Items of significance yielding lower levels of compliance are itemized in Tables 5 and 6. With respect to specimen collection and transport, suboptimal compliance was noted in the donning of lead gowns by laboratorians assisting in the procurement of computed tomography (CT)-guided bone marrow or fine-needle aspiration specimens (Table 5). Of 96 respondents utilizing transit tubes (such as pneumatic tube systems), almost 30% did not have a remediation procedure in the event of breakage. With respect to specimen processing and handling, nearly 80% of the respondents reported having at least two individuals who were certified in the packaging and shipping of infectious substances. However, less than 70% of these respondents possessed documentation of this training and ensured subsequent competency.

Common compliance deficiencies with respect to not covering biohazardous waste receptacles when not in use and not using freezer gloves for protection when entering a freezer were observed over a wide range of disciplines. Deficiencies particularly tended to occur in areas of the laboratory that perform microbiological techniques outside traditional culture interpretation (Table 5). While 94.2% of the laboratories in general reported utilizing a biosafety cabinet for culture processing, only 28.2% of the respondents processed specimens for non-AFB-related direct microscopic examination in a biosafety cabinet when they were cognizant of the fact that AFB studies of the specimen were also requested. Sections of the laboratory performing direct microscopic examination also yielded compliance rates of <80% for the proper management of discarded materials. Sections of the laboratory participating in screening cultures (in which either a specific microbe is isolated using chromogenic/selective medium or the growth obtained by cultivation techniques is referred to another laboratory for iden-

TABLE 1 (Continued)

[a]Data are for 103 respondents.
[b]Nonmolecular, nonserology testing for *Cryptococcus* spp. (17.5%), *Campylobacter* spp. (12.6%), fecal inflammatory markers (8.7), *Plasmodium* spp. (6.8%), human immunodeficiency virus (6.8%), mononucleosis (Monospot assay; 5.8%), *Trichomonas vaginalis* (3.9%), *Helicobacter pylori* (3.9%), and central nervous system bacterial antigens (1.9%).
[c]Includes the use of colorimetric screening media or screening cultures with the goal of discarding negative plates and sending positive plates to a reference laboratory.
[d]Includes screens for methicillin-susceptible *Staphylococcus aureus*, *Streptococcus agalactiae*, yeast, fluoroquinolone-resistant Gram-negative bacilli, multidrug-resistant Gram-negative bacilli, vancomycin-resistant *Enterococcus* spp., and environmental organisms (endoscopes).

TABLE 3 Percent compliance with individual BSL-1 requirements, WCLN risk assessment survey respondents, 2016[a]

Requirement[b]	% compliance
Laboratory design compatible with cleaning[c]	89.3
Hand-washing sink near laboratory exit	89.3
Effective pest management program	82.5
Decontamination of cultures and other infectious materials before disposal	76.7
Screens on windows opening to the exterior (if present)	69.9
Placement of a biohazard sign at the entrance when infectious agents are present	61.2

[a]Data are for 103 respondents.

[b]Requirements that are not specifically listed here but that met a >90% rate of compliance among the respondents included (in order of increasing compliance) benchtops impervious to water and resistant to heat, organic solvents, and other chemicals; access to laboratory controlled by doors; safe handling of sharps; procedures to minimize splashes and/or aerosols; decontamination of work surfaces; availability of personal protective equipment; prohibition of food, drink, smoking, cosmetic application, and contact lens handling; availability of mechanical pipetting devices; and appropriate personnel training regarding duties and prevention of exposure.

[c]Examples include nonporous chair coverings and the absence of carpets and rugs.

tification) often failed to employ proper personal protective equipment during various phases of culture management.

Many opportunities for improvement in the microbiology laboratories were related to the manipulation of particularly hazardous organisms. Of all the respondents, 75.4% reported performing potentially aerosol-generating work with high-risk bacterial pathogens in a functional biosafety cabinet using BSL-3 practices (controlled access to the area when work is in progress; decontamination of all waste; wearing of a solid-front gown with cuffed sleeves, gloves, and an N-95 respirator; Table 6). A total of 76.5% of the respondents reported that all work with AFB was performed with BSL-3 practices. Approximately one-half of the work with suspect systemic fungi was accompanied by the use of BSL-3 practices, and less than 75% of the respondents visually notify fellow laboratorians of ongoing work with these suspect cultures.

Other task assessments came under the auspices of additional preferred mitigation control measures. Within the realm of specimen collection and transport, 9.2% of 98 respondents utilized optimal protective eyewear during phlebotomy for the collection of blood for culture (data not illustrated), while 46.9% disinfected areas where blood is drawn when the patient is known to harbor an organism of nosocomial significance. Less than 40% of the respondents inquired about a significant travel history before specimen procurement. With respect to specimen processing and handling, 46.0% of the respondents processed all microbiology-related specimens in a biosafety cabinet; in

TABLE 4 Percent compliance with additional requirements constituting BSL-2 status, WCLN risk assessment survey respondents, 2016[a]

Requirement[b]	% compliance
Have self-closing doors that may be locked to control access	89.3
Decontaminate potentially hazardous laboratory waste before disposal	82.1
Advise persons entering laboratory about potential hazards or have them meet specific entry/exit requirements	78.6
Open centrifuge safety carriers only in a biosafety cabinet	72.6
Have an automatic or manually operated hands-free hand-washing sink	71.4
Protect vacuum lines with HEPA filters or equivalent	59.5

[a]Data are for 84 respondents.

[b]Requirements not specifically listed in Table 4 that met a >90% rate of compliance among the respondents included (in order of increasing compliance) the availability of a biosafety manual, prohibition of plants from the laboratory, removal of personal protective equipment prior to leaving for nonlaboratory areas, decontamination of laboratory equipment after splashes with contaminated material and on a routine basis, performance of procedures involving manipulation of infectious materials that may generate an aerosol in a class II biosafety cabinet, offering of immunizations and medical surveillance to laboratory personnel, demonstration of competency in standard and special microbiology practices, and immediate evaluation and documentation of exposure incidents (with treatment provision).

TABLE 5 Selected functions reflective of required microbiology mitigation controls, with percent compliance among WCLN risk assessment survey respondents, 2016

Required mitigation control	No. of qualified respondents	% compliance
Wear a lead gown when assisting with CT-guided:		
Fine-needle aspiration	39	59.0
Bone marrow aspiration	60	45.0
Have a procedure for remediation of transit tube breakage	96	70.8
Document packaging/shipping certification for two laboratorians	82	68.3
Provide refresher packaging/shipping training (plus competency) every 2 yr	82	62.2
Split primary specimen for AFB/fungus culture in biosafety cabinet	100	68.0
Cover partially filled waste receptacles when not used		
Nonmolecular, nonserologic assays	98	82.7
Direct microscopic examination	89	65.2
Screening cultures	59	74.6
Culture interpretation	52	82.7
Use freezer gloves for specimen storage		
Specimen processing and handling	95	42.1
Nonmolecular, nonserologic assays	97	52.6
Screening cultures	60	55.0
Culture interpretation	54	57.4
Process specimens for direct microscopic examination in a biosafety cabinet when specimen also requires testing for AFB	103	28.2
Double-bag waste (direct microscopic examination)	89	78.7
Ensure that the sharps container does not exceed 2/3 vol (direct microscopic examination)	89	79.8
Use proper personal protective equipment (culture setup)	93	84.9
Follow written procedures (screening cultures)	103	54.4
Wear a laboratory coat (screening cultures)	103	52.4
Use proper personal protective equipment during culture retention (screening cultures)	60	26.7

terms of microbiology culture requisitions, 60.2% of the laboratories processed the specimens in a biosafety cabinet. A total of 48.5% of the available biosafety cabinets possessed an audible airflow alarm.

A total of 26.0% of the respondents performing specimen processing and handling reported the use of an additional preferred mitigation control measure in which

TABLE 6 Selected functions more reflective of required microbiology mitigation controls in the traditional microbiology culture interpretation setting with percent compliance among WCLN risk assessment survey respondents, 2016

Required mitigation control	No. of qualified respondents	% compliance
Perform aerosol-generating work in a biosafety cabinet with BSL-3 practices (high-risk bacterial pathogen)	61	75.4
Perform all work with AFB in a biosafety cabinet with BSL-3 practices	17	76.5
Perform all potential work with systemic fungi in a biosafety cabinet with BSL-3 practices	22	54.5
Perform all culture work with suspect or highly pathogenic viruses in a biosafety cabinet with BSL-3 practices	3	33.3
Post a sign warning others when working with systemic fungus cultures	22	50.0
Post a sign warning others when working with AFB cultures	17	70.6
Decontaminate waste (including liquid) from highly pathogenic microbes prior to disposal	52	69.2

specimen tubes are uncapped with the assistance of gauze or a suitable disinfectant (data not illustrated); 27.0% of the respondents donned additional personal protective equipment when the specimen is known to emanate from a patient housed under aerosol or droplet precautions. Similar percentages of respondents reported that they performed these additional mitigation control measures in the context of rapid nonmolecular, nonserology assays. Should these assays require mixing or vortexing, 47.5% of the respondents performed these steps in a biosafety cabinet. Of the 103 respondents performing direct microscopic examination, 35.0% prepared the slides in a biosafety cabinet. A total of 18.4% added BSL-3 practices if the specimen is known to emanate from a patient housed under aerosol or droplet precautions.

DISCUSSION

Proper biosafety practices and mitigation control measures are essential elements of a culture of laboratory biosafety to protect laboratory professionals from significant exposures and laboratory-acquired infections. A heightened awareness of the need for a strong culture of laboratory biosafety has arisen in response to the increasing potential for encountering highly virulent and/or highly antimicrobial-resistant organisms in routine clinical practice (23), making sentinel observations of purported bioterrorism agents (24), and properly managing biological select agents (25). The assurance of biosafety is not restricted to facility-related provisions or other engineering controls; human behaviors also contribute to the implementation of a culture of laboratory biosafety. An international survey of 23 BSL-3 and -4 facilities (26) revealed that while the incidence of laboratory-acquired infections was extremely low, the underlying cause for nearly 80% of these laboratory-acquired infections was human error. Taken together, one element crucial to a culture of laboratory biosafety is identification of a champion for this cause in each individual laboratory. This individual may have the title of medical director, certified clinical microbiologist, principal investigator, or dedicated laboratory biosafety officer and must demonstrate commitment to ongoing staff education, training, and proficiency monitoring.

The performance of a biosafety risk assessment constitutes an important initial measure to ensure this culture of biosafety. A standardized risk assessment questionnaire (inclusive of applicable definitions, required standards, and optimal mitigation controls) was distributed to laboratorians at 150 WCLN sites. The advantages of distributing this tool in such a manner include the opportunity for bench-level laboratorian participation in the completion of the risk assessment questionnaire. Past surveys conducted in the context of hospital safety (27, 28) have demonstrated that laboratorians are more apt than physicians or nonclinical hospital employees to answer the questions that have been posed in a less positive fashion and to delineate infrastructure deficiencies. When extrapolated to the current survey, the implied greater knowledge of current state of practice and/or the genuine frankness of the response from laboratorians would contribute to a baseline of data on which educational or improvement efforts may be developed. Another strength of this project is that the information obtained is generalizable to both clinical laboratories and laboratory networks in other states and regions because of the broad scope of the laboratories surveyed. The 103 laboratories that provided responses to the questionnaire ranged from those performing 16,000 billable tests per year to those performing up to 5.3 million billable tests per year, served various levels of acuity, and were distributed in both rural and urban regions of Wisconsin (56% of the laboratories were located in communities with populations of less than 25,000). Nearly all respondents were engaged in activities related to specimen collection and transport; over 90% processed primary clinical specimens for routine bacterial, fungus, AFB, and/or virus culture (Table 1).

Overall data from this exercise indicate a reasonable level of compliance with required and best practice mitigation controls within the network of clinical laboratories surveyed. In terms of task assessment, over 88% of the respondents fell within compliance for more than three-quarters of the required mitigation control measures

listed in the risk assessment. At the same time, the opportunities for laboratory biosafety improvement identified include those related to the acquisition of the patient/clinical history for certain primary clinical specimens (Table 2), the discernment of laboratory biosafety level status (Tables 3 and 4), the performance of microbiology-related tasks by laboratory generalists (Table 5), and the manipulation of specimens derived from certain at-risk patients (such as those with infections with systemic fungi or *Mycobacterium* spp.; Table 6). At the same time, it should be noted that reference, public health, and other tertiary laboratories may not have direct access to data regarding the infection control or isolation status of certain patients.

A number of factors could explain the decreased rates of compliance with certain aspects of the risk assessment. It is possible that the yes/no format for providing answers to the risk assessment questionnaire may have limited the ability of the respondents to answer certain questions to the fullest degree of accuracy because of variable circumstances at a given institution. As an example, in the context of BSL-1 practices, less than 80% of the respondents reported that they decontaminated cultures, stocks, and other infectious materials prior to disposal. It is possible that laboratories that reported noncompliance with this questionnaire item instead ship biohazardous waste to an off-site decontamination facility for disposal through a commercial vendor. Other items within the risk assessment may have been subject to misinterpretation or other mitigating circumstances that could not be captured through the format used for questioning.

Decreased rates of compliance with elements of a biosafety risk assessment may additionally be a function of complacency within the laboratory. Complacency can be defined as a human risk factor that is a result of boredom and a lack of responsible leadership. Managerial or peer accountability is one means of controlling for complacency (Sean Kaufman, Behavioral-Based Improvement Solutions, personal communication). An observation of 93 laboratorians employed across 21 BSL-2 facilities at a U.S. university documented an average of 2.6 hand-to-face contacts per working hour, with over 80% of these contacts involving the nose or forehead (29). The frequency of such contacts was determined to be a function of the perception of an infectious risk, as workers who perceived that greater health risks were associated with the agent(s) studied in the particular laboratory were less likely to touch their face. In 2016, CDC revealed a national tuberculosis incidence rate of 2.9 cases per 100,000 persons, with the incidence rate in Wisconsin being 0.7 cases per 100,000 persons (30), which was the lowest among the five states constituting the East North Central division. Nearly two-thirds of the culture-confirmed tuberculosis cases in Wisconsin emanate from the top two population centers of the state (Laura Louison, WSLH, personal communication). Therefore, the low prevalence of tuberculosis in most regions of Wisconsin and the perceived low risk of laboratory-acquired infection due to *Mycobacterium tuberculosis* may translate into a sense of laboratory complacency for some and contribute to selected lower rates of compliance with the traditional microbiology laboratory items assessed in Table 6.

Finally, intrinsic knowledge and educational efforts can contribute to a general culture of laboratory biosafety. Odetokun et al. (31) reported that 5.4% of participants in a survey of Nigeria veterinary laboratories demonstrated a satisfactory knowledge of laboratory biosafety and security, while 94.6% demonstrated poor knowledge. Among the researchers, 25.7% and 74.3% were documented to have high and low levels of awareness about biosafety, respectively. Ghanchi et al. (32) reported 40%, 66%, and 74% rates of acknowledgment of the importance of disinfection, personal protective equipment, and biohazardous waste disposal, respectively, as part of biosafety practices during antimicrobial susceptibility testing in Pakistani clinical laboratories. A risk assessment of gain-of-function research (33) acknowledged gaps in knowledge about biosafety in the United States and concluded that governments should invest a fraction of their funding support in the prevention of biological accidents and subsequent laboratory-acquired infections. While the degrees of education and vocational requirements can vary globally, it is imperative that microbiologists develop and maintain competency in facets of biosafety, including those related to updates in mitigation control practices.

In summary, while some of the aforementioned limitations may have impacted the data analysis, the data presented here represent an appropriate baseline for future efforts to improve laboratory biosafety in Wisconsin. Current activities of LabTAG with respect to this biosafety endeavor include discussion of the findings and focused refresher training on the basics of biosafety with members of the WCLN. In addition, a follow-up risk assessment exercise is planned. This follow-up is necessary on the basis of the fact that several elements of laboratory biosafety were either unbeknownst to or not implemented by the laboratories. If improvements are noted, attempts will be made to determine whether completion of the initial risk assessment resulted in changes in biosafety-related practices. If significant improvements are not noted, additional studies may be necessary to determine whether clinical laboratories handle biosafety as stringently as they could or if completion of a risk assessment is worth the time expended by laboratories in a practical sense. Ultimately, data emanating from this risk assessment tool may be generalizable to other locations and assist with identifying facility- and process-based improvements that will increase vigilance toward biosafety among both microbiologists and laboratory generalists and properly prepare them for routine and aberrant scenarios.

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