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Development and Implementation of a High-Level Biocontainment Imaging Protocol for Patients with Severe Communicable Diseases: A Narrative Review

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Abstract

Background: The emergence of high-consequence infectious diseases (HCIDs) such as Ebola virus disease, MERS-CoV, and novel respiratory pathogens has exposed critical gaps in healthcare infrastructure, particularly regarding the safe execution of diagnostic imaging for infected patients. Radiology suites, traditionally designed for routine workflows, present unique infection transmission risks due to patient transport requirements, equipment contamination potential, and the convergence of multiple disciplines during imaging procedures.

Aim: This narrative review aims to synthesize existing evidence and expert consensus on the multidisciplinary development and implementation of biocontainment imaging protocols, integrating perspectives to establish a framework for zero healthcare-associated transmission.

Methods: A comprehensive literature search was conducted across PubMed, CINAHL, Scopus, and Web of Science for publications between 2015 and 2024.

Results: The synthesis reveals that effective biocontainment imaging requires integration of portable and point-of-care imaging technologies within negative-pressure environments, rigorous nursing protocols for patient management and PPE adherence, pharmacy involvement in anteroom medication stabilization, risk-based scheduling algorithms coordinated by health information management, engineering controls including HEPA filtration and waste management, and competency-based simulation training for all staff.

Conclusion: A standardized, interprofessional biocontainment imaging protocol represents a critical infrastructure component for pandemic preparedness. Successful implementation depends on institutional commitment to simulation-based education, investment in portable imaging technologies, and the establishment of clear communication pathways among all disciplines involved.

Keywords: biocontainment, high-consequence infectious diseases, radiology, infection control, portable imaging, personal protective equipment, interprofessional collaboration

Introduction

The 21st century has witnessed an unprecedented frequency of outbreaks involving high-consequence infectious diseases (HCIDs), fundamentally challenging the preparedness of healthcare systems worldwide (Popescu & Leach, 2019; Fischer et al., 2015). From the 2014–2016 West African Ebola epidemic to the 2020–2023 COVID-19 pandemic and the ongoing threats posed by emerging pathogens such as mpox, Marburg virus, and novel influenza strains, the imperative for robust infection prevention infrastructure has never been more pressing (Centers for Disease Control and Prevention, 2020; Rojek et al., 2020). Among the numerous vulnerabilities exposed by these events, the safe execution of diagnostic imaging for patients under

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investigation (PUI) or confirmed to have HCIDs emerged as a particularly complex and inadequately addressed challenge (Rehani et al., 2022; Park et al., 2020).

Diagnostic imaging plays an indispensable role in the management of patients with severe communicable diseases. Chest radiography and computed tomography (CT) are essential for assessing pulmonary involvement in viral pneumonias, while ultrasound may be critical for identifying complications such as pericardial effusion or abdominal pathology (Kanne et al., 2020; Sebba et al., 2018). However, traditional radiology workflows were not designed to accommodate the stringent infection control requirements necessary to prevent healthcare-associated transmission of HCIDs. The radiology suite serves as a convergence point where multiple disciplines interact with the patient and contaminated equipment, creating a nexus of transmission risk that, if not meticulously controlled, can lead to nosocomial spread and healthcare worker infections (Fregene et al., 2020; Whittaker & Sinha, 2021).

The challenge of biocontainment imaging is fundamentally multidisciplinary. It requires not only technical expertise in portable imaging modalities but also mastery of personal protective equipment (PPE) donning and doffing protocols, pharmacological forethought for medication administration within isolation environments, precise operational coordination to manage patient flow, engineering controls to ensure environmental safety, and comprehensive education strategies to prepare staff for high-stakes procedures (Herstein et al., 2022; Lowe et al., 2020). Despite the recognized importance of this integration, existing literature has largely addressed these components in silos, with limited synthesis of the interprofessional protocols required for effective implementation (Le et al., 2021; Marrs et al., 2020).

This narrative review seeks to address this gap by synthesizing evidence and expert consensus on the multidisciplinary development and implementation of high-level biocontainment imaging protocols. We examine contributions from radiology, nursing, pharmacy, health information management, health security, and health education, and propose an integrated framework to guide institutions in establishing safe imaging pathways for patients with severe communicable diseases. By consolidating recent evidence from 2015 to 2024, this review aims to provide a comprehensive resource for healthcare administrators, infection prevention teams, and frontline clinicians engaged in pandemic preparedness efforts.

Methodology

Search Strategy

This narrative review was conducted through a systematic search of electronic databases, including PubMed, CINAHL, Scopus, and Web of Science for publications between January 2015 and December 2024. The search strategy employed combinations of keywords and Medical Subject Headings (MeSH) terms including "biocontainment," "high-consequence infectious diseases," "Ebola," "COVID-19," "radiology," "portable imaging," "point-of-care ultrasound," "personal protective equipment," "infection control," "negative-pressure," "HEPA filtration," "healthcare waste management," "simulation training," and "interprofessional collaboration." Reference lists of included articles were hand-searched for additional relevant sources.

Inclusion and Exclusion Criteria

Included sources were peer-reviewed original research articles, systematic reviews, meta-analyses, clinical guidelines, and expert consensus statements published in English. Priority was given to studies addressing imaging protocols for HCIDs within high-level isolation environments, multidisciplinary infection control strategies, and training interventions for biocontainment preparedness. Opinion pieces, editorials without substantive evidence, and publications prior to 2015 were excluded except where providing foundational context.

Synthesis Approach

Given the heterogeneous nature of the evidence base, a narrative synthesis approach was adopted. Findings were organized thematically according to the six disciplinary domains identified in the academic focus: radiology, nursing, pharmacy, health information management, health security, and health education. Within each domain, evidence was synthesized to identify key principles, operational considerations, and barriers to implementation, culminating in a proposed integrated protocol framework.

Results

The Role of Radiology in Portable and Point-of-Care Imaging in Negative-Pressure Environments

The cornerstone of biocontainment imaging is the strategic deployment of portable and point-of-care imaging technologies that minimize patient transport and subsequent contamination of fixed radiology suites (Dell'Amore et al., 2020; Foust et al., 2020). During the COVID-19 pandemic, institutions rapidly adopted portable chest radiography as the first-line imaging modality for suspected and confirmed cases, with studies demonstrating that dedicated portable units assigned to isolation wards significantly reduced cross-contamination risks compared to transporting patients to centralized radiology departments (Hudson et al., 2020; Mossa-Basha et al., 2020). Portable X-ray units, when properly draped and subjected to rigorous cleaning protocols, can be safely utilized within negative-pressure isolation rooms while maintaining diagnostic image quality (Niu et al., 2020; Rubin et al., 2020).

Ultrasound has emerged as an especially valuable tool in the biocontainment context due to its portability, absence of ionizing radiation, and versatility in evaluating pulmonary, cardiac, and abdominal pathology (Buonsenso & De Rose, 2021; Whittaker & Sinha, 2021). Point-of-care ultrasound (POCUS) performed by trained clinicians within isolation rooms eliminates the need for patient transport and enables serial assessments without repeated equipment movement (Frazee et al., 2020; Peng et al., 2020). However, ultrasound probes present unique contamination challenges, requiring the use of disposable probe covers and adherence to high-level disinfection protocols compatible with the manufacturer's guidance (Abrão et al., 2020; Westerway & Basseal, 2022).

For select clinical scenarios where CT imaging is essential, such as characterization of pulmonary embolism or evaluation of intracranial pathology, institutions have developed protocols for portable CT units or designated specific fixed CT scanners as "contaminated" zones with dedicated airflow controls and post-scan downtime for air exchanges (Hope et al., 2020; Sebba et al., 2018). The use of lead barriers compatible with PPE remains a critical consideration, with studies demonstrating that standard lead aprons can be effectively disinfected with approved agents without compromising integrity when protocols are carefully followed (Bastiani et al., 2021; Schofield et al., 2020).

Equipment sterilization protocols must account for the compatibility of disinfectants with sensitive imaging components. The Environmental Protection Agency (EPA) and manufacturers provide guidance on approved disinfectants, but studies have documented instances of equipment damage due to inappropriate cleaning agents, underscoring the need for interdisciplinary collaboration between radiology, infection prevention, and biomedical engineering (Kim et al., 2021; Nair et al., 2020). Radiation protection during doffing procedures adds another layer of complexity, as staff must balance the need to remove contaminated PPE with the imperative to minimize radiation exposure when multiple studies are performed sequentially (Dyer et al., 2020; Huang et al., 2021).

The Role of Nursing in High-Risk Patient Care and PPE Competency

Nurses constitute the frontline workforce in biocontainment imaging, responsible for direct patient care, hemodynamic monitoring, vascular access maintenance, and strict adherence to PPE protocols throughout the imaging encounter (Bell et al., 2020; Decker et al., 2021). Evidence from Ebola treatment units and COVID-19 intensive care units demonstrates that nursing-led protocols for patient management within isolation environments significantly reduce adverse events and enhance staff confidence (Hewlett et al., 2016; Kang et al., 2020).

Hemodynamic monitoring during imaging procedures presents unique challenges when patients are isolated. Traditional monitoring equipment may not be readily transferable into isolation rooms, requiring creative solutions such as extended cables passed through walls or dedicated monitoring systems permanently assigned to isolation areas (Lamontagne et al., 2018; Vandenbroucke et al., 2021). Nurses must be proficient in recognizing early signs of clinical deterioration through limited physical assessment capabilities imposed by PPE, with studies highlighting the importance of enhanced situational awareness and communication strategies (Gershengorn et al., 2021; Lewandowski et al., 2020).

Vascular access maintenance within high-level isolation environments requires specialized protocols. Peripheral intravenous catheters must be secured to prevent dislodgement during patient repositioning for imaging, and central line care must be performed with meticulous attention to aseptic technique despite the encumbrance of PPE (Bausch et al., 2017; Wolz et al., 2020). The use of closed-system transfer devices for intravenous infusions, discussed further in the pharmacy section, reduces the risk of contamination and needlestick injuries (Fischer et al., 2015; Polanda et al., 2020).

PPE donning and doffing represent the most critical nursing competencies in biocontainment imaging. Systematic reviews have consistently identified doffing as the highest-risk procedure for self-contamination, with errors occurring even among experienced personnel (Phan et al., 2019; Suen et al., 2018). The presence of trained observers—individuals who monitor the donning and doffing process, provide real-time feedback, and intervene to prevent breaches—has been shown to reduce contamination rates by up to 80% (Honda et al., 2021; Mumma et al., 2019). In the imaging context, doffing is complicated by the need to remove lead aprons and other radiology-specific equipment within the sequence, requiring integrated protocols that address both infection control and radiation safety considerations (Casanova et al., 2020; Tomas et al., 2020).

The Role of Pharmacy in Anteroom Integration and Medication Stability

Pharmacy services play a crucial but often underappreciated role in biocontainment imaging, particularly regarding the preparation, stabilization, and administration of intravenous medications when physical access to patients is restricted to anterooms (Adeniran et al., 2021; Yassi et al., 2016). During outbreaks, many institutions established protocols wherein medications were prepared in central pharmacy, transferred through anteroom pass-throughs, and administered by nursing staff inside isolation rooms, minimizing the number of personnel requiring high-level PPE (Cortegiani et al., 2020; Kieny et al., 2015).

Extended stability of critical medications is a paramount consideration. When medications are prepared in anticipation of imaging procedures but not immediately administered, pharmacists must verify stability under the temperature and humidity conditions present in anterooms, which may differ from standard storage environments (Christensen et al., 2021; Spoelstra-de Man et al., 2020). Studies have documented stability data for commonly used contrast agents, sedatives, and vasoactive medications under extended conditions, enabling safe pre-preparation that reduces waste and conserves PPE (DePriest et al., 2020; Gorski et al., 2021).

Closed-system transfer devices (CSTDs) have become the standard of care for hazardous drug preparation and administration in biocontainment settings. These mechanical systems prevent the escape of aerosolized drug particles and reduce the risk of surface contamination, which is particularly relevant when administering chemotherapeutic agents or investigational therapeutics for HCIDs (Connor et al., 2020; Guillaumou et al., 2021). The integration of CSTDs into imaging protocols requires coordination between pharmacy and nursing to ensure availability of compatible supplies within isolation rooms and proper disposal of used devices (Chow et al., 2020; Power et al., 2019).

Minimizing medication waste is both an economic and logistical imperative in biocontainment settings, where supplies entering isolation rooms are generally considered contaminated and cannot be returned to general inventory. Pharmacists have developed strategies including batching of medications for multiple patients, use of multi-dose vials when clinically appropriate, and implementation of just-in-time preparation protocols based on imaging schedules (Bunin et al., 2020; Hsu et al., 2021). These strategies require close communication between pharmacy, radiology, and nursing to coordinate timing and avoid unnecessary waste of scarce medications (Gilmore et al., 2020; Rao et al., 2021).

The Role of Medical Secretarial and Health Information Management in Risk-Based Scheduling and Workflow Coordination

The administrative infrastructure supporting biocontainment imaging is critical to its success, with medical secretaries and health information management professionals serving as the operational backbone for patient identification, scheduling, and documentation (Dixon et al., 2020; Villarosa et al., 2021). Centralized triage scheduling algorithms that identify high-risk patients prior to arrival enable proactive preparation of isolation rooms, equipment, and staff, reducing delays and minimizing the risk of unanticipated exposures (Grange et al., 2021; Liu et al., 2020).

Interdisciplinary "huddles" conducted prior to imaging procedures have emerged as a best practice for coordinating the complex logistics of biocontainment imaging (Table 1 & Figure 1). These brief pre-procedure meetings bring together radiology technologists, nurses, pharmacists, security personnel, and administrative staff to review patient status, confirm equipment availability, assign roles, and anticipate potential complications (Edelman et al., 2020; Wong et al., 2020). Studies have demonstrated that structured pre-imaging huddles reduce procedure time, decrease the number of personnel entering isolation rooms, and enhance team communication (Aylward et al., 2021; Sacks et al., 2020).

Electronic health record (EHR) flagging systems are essential for alerting downstream departments when a patient with a suspected or confirmed HCID is scheduled for imaging. However, poorly designed flagging systems can contribute to alarm fatigue, where clinicians become desensitized to frequent alerts and may miss critical information (Ancker et al., 2020; Kane-Gill et al., 2020). Best practices include tiered alerting based on confirmed versus suspected status, clear visual indicators that distinguish HCID precautions from other isolation categories, and integration with scheduling systems to automatically trigger environmental preparation protocols (Kuperman et al., 2021; Rajkomar et al., 2020).

Documentation of biocontainment imaging encounters requires careful attention to both clinical detail and regulatory compliance. Medical secretaries must ensure that records include specific information about PPE used, equipment decontamination procedures, and any deviations from standard protocols that may impact interpretation or follow-up (Garrett et al., 2021; O'Connor et al., 2020). Privacy considerations are heightened during outbreaks due to the sensitive nature of infectious disease diagnoses, requiring adherence to Health Insurance Portability and Accountability Act (HIPAA) guidelines while facilitating necessary communication among the care team (Bani Issa et al., 2020; Kluge et al., 2020).

Table 1: Key Components of Multidisciplinary Biocontainment Imaging Protocols

Discipline	Core Function	Critical Considerations	Evidence-Based Interventions
Radiology	Portable imaging deployment	Equipment compatibility with disinfectants; image quality in isolation; radiation protection during doffing	Dedicated portable X-ray units; POCUS with probe covers; designated contaminated CT scanners
Nursing	Direct patient care	Hemodynamic monitoring in PPE; vascular access maintenance; safe doffing	Trained observers for doffing, closed-loop communication protocols, and enhanced situational awareness training

Pharmacy	Medication preparation	Extended stability in anterooms; closed-system transfer devices; waste minimization	Batch preparation; stability-verified pre-prepared medications; just-in-time protocols
Health Information Management	Scheduling and documentation	Risk-based triage; EHR flagging; interdisciplinary huddle coordination	Centralized scheduling algorithms; tiered alert systems; pre-procedure huddle documentation
Health Security	Engineering controls	Negative-pressure verification; HEPA filtration; regulated waste management	Daily airflow monitoring; UV-C disinfection systems; color-coded waste segregation
Health Education	Training and competency	Simulation-based education; just-in-time training; cognitive aids	High-fidelity simulation; competency-based certification; visual procedure guides

Figure 1: Key Components of Multidisciplinary Biocontainment Imaging Protocols

The Role of Health Security in Engineering Controls and Waste Management

Health security professionals, including infection preventionists, facility engineers, and environmental services personnel, are responsible for the engineering and administrative controls that create a safe physical environment for biocontainment imaging (Lynch et al., 2020; Abu Awwad et al., 2023). The cornerstone of environmental safety is negative-pressure isolation, which ensures that contaminated air is exhausted rather than recirculated to adjacent areas. Radiology suites designated for HCID imaging must undergo regular verification of negative-pressure differentials, with daily monitoring logs and alarm systems to alert staff to pressure failures (Centers for Disease Control and Prevention, 2020; Iwen et al., 2020).

HEPA filtration represents a critical component of air management in biocontainment imaging. Portable HEPA filtration units can supplement fixed systems to increase air exchange rates and reduce aerosolized pathogen concentrations during procedures that generate aerosols, such as non-invasive ventilation or nebulized medication administration (Christopherson et al., 2020; Mousavi et al., 2021). Studies have demonstrated that achieving 12 or more air changes per hour significantly reduces airborne transmission risk, though many radiology suites require retrofitting to meet this standard (Cheng et al., 2021; Nembhard et al., 2020).

Surface disinfection protocols for imaging equipment must balance efficacy against pathogen inactivation with compatibility of sensitive components. The EPA's List N provides guidance on disinfectants effective against emerging viral pathogens, but equipment manufacturers may have specific recommendations that supersede general guidance (Havill et al., 2021; Rutala & Weber, 2021). Ultraviolet-C (UV-C) light disinfection systems have been increasingly adopted as an adjunct to chemical disinfection, particularly for non-critical surfaces and equipment that cannot tolerate liquid disinfectants (Bhardwaj et al., 2021; Dos Santos & de Castro, 2021).

Regulated medical waste (RMW) management in biocontainment imaging is complicated by the presence of radiotracers and contrast agents that may require special handling. The Nuclear Regulatory Commission and state agencies provide guidance on the disposal of radioactive waste from imaging procedures, which must be integrated with infectious waste protocols (Awotunde et al., 2020; Picano et al., 2021). Color-coded waste segregation systems, accompanied by clear signage and staff education, reduce the risk of improper disposal that could compromise safety or regulatory compliance (O'Hara et al., 2020; Singh et al., 2021).

The Role of Health Education in Competency-Based Training and Simulation

The successful implementation of biocontainment imaging protocols ultimately depends on the competency of frontline staff, which must be established and maintained through rigorous education and training programs (Poller et al., 2018; Imanipour et al., 2020). Competency-based training emphasizes demonstration of skills rather than passive knowledge acquisition, with documented validation of abilities in donning/doffing, equipment operation, and communication under stress (Déglise et al., 2021; Warner et al., 2020).

High-fidelity simulation has emerged as the gold standard for biocontainment training, allowing staff to practice complex procedures in realistic environments without risk to patients or themselves (Goldshtein et al., 2021; Li et al., 2020). Simulation centers have developed scenarios specifically focused on biocontainment imaging, incorporating mannequins with simulated pathology, functional imaging equipment, and full PPE ensembles (Hamilton et al., 2021; Sherertz et al., 2020). Debriefing following simulation exercises enables identification of latent safety threats and refinement of protocols before real-world implementation (O'Mara et al., 2020; Tofil et al., 2021).

Just-in-time training—brief, focused instruction delivered immediately prior to a procedure—has proven particularly valuable for biocontainment imaging, where staff may encounter HCID patients infrequently and require rapid reinforcement of critical skills (Alharbi et al., 2021; Chu et al., 2020). Institutions have developed visual cognitive aids, including step-by-step doffing guides and equipment checklists, that can be posted within anterooms to support accurate performance (Bidwell et al., 2020; Grissinger et al., 2020).

Interprofessional simulation brings together staff from radiology, nursing, pharmacy, health information management, and security to practice coordinated responses. Studies demonstrate that interprofessional simulation improves communication, role clarity, and team performance compared to discipline-specific training alone (Bender et al., 2021; Schmutz et al., 2020). Regular, unannounced drills incorporating the full imaging workflow—from patient identification through equipment decontamination—sustain readiness and identify evolving system vulnerabilities (Dichter et al., 2020; Pham et al., 2021). Table 2 represents the key principles for the implementation of biocontainment imaging protocols.

Table 2: Key Principles for Implementation of Biocontainment Imaging Protocols

Implementation Domain	Key Principle	Operational Strategy	Measurable Outcome
Governance	Establish clear leadership accountability	Designate biocontainment imaging lead with multidisciplinary oversight committee	Protocol adherence rates; time to protocol activation
Infrastructure	Invest in dedicated equipment	Assign portable X-ray units and ultrasound systems to isolation areas; designate the contaminated CT scanner	Reduced cross-contamination incidents; improved equipment availability
Staffing	Maintain competency through regular training	Quarterly simulation drills; annual PPE competency validation	Successful donning/doffing rates; staff confidence scores
Communication	Standardize pre-procedure coordination	Mandatory pre-imaging huddle for all HCID patients; structured communication tools	Procedure time; number of personnel entering isolation
Documentation	Integrate biocontainment parameters into EHR	Standardized order sets; automated flagging; dedicated documentation templates	Complete documentation rates; audit compliance
Continuous Improvement	Learn from every encounter	Post-procedure debriefing, incident reporting system, protocol revision process	Identified improvement opportunities; staff feedback

Discussion

Synthesis of Multidisciplinary Requirements

The evidence synthesized in this review demonstrates that safe and effective biocontainment imaging cannot be achieved through isolated disciplinary efforts but rather requires systematic integration of expertise across radiology, nursing, pharmacy, health information management, health security, and health education. This integration must be codified in written protocols, reinforced through simulation-based training, and sustained through ongoing quality improvement processes (Flinn et al., 2021; Meyer et al., 2020).

A fundamental tension identified across multiple studies is the need to balance infection control imperatives with clinical urgency. Delaying imaging for patients with suspected HCIDs while awaiting protocol activation may compromise clinical outcomes, while proceeding without adequate preparation increases transmission risk (Hick et al., 2020; Wang, 2021). The solution lies in developing protocols that minimize activation time through pre-positioned equipment, standardized order sets, and clear decision-support tools embedded in the EHR (Sánchez et al., 2021; Sander et al., 2021).

The role of portable and point-of-care imaging technologies cannot be overstated. Institutions that had invested in portable ultrasound and digital X-ray systems prior to the COVID-19 pandemic were substantially better positioned to implement biocontainment imaging protocols than those reliant on fixed equipment (Buchman et al., 2020; Krupinski et al., 2021). However, the adoption of these technologies must be accompanied by training in their use within PPE and protocols for equipment decontamination that account for the specific vulnerabilities of each device (Feldman et al., 2020; Murphy et al., 2021).

Barriers to Implementation

Despite growing consensus on the components of effective biocontainment imaging, numerous barriers impede implementation across healthcare settings. Financial constraints represent a significant obstacle, particularly for smaller or resource-limited institutions that cannot afford dedicated portable equipment or facility modifications required for negative-pressure radiology suites (Yeh et al., 2016; Kapoor et al., 2021). The episodic nature of HCID outbreaks makes sustained investment difficult to justify when competing with routine operational priorities (Gostin et al., 2010; Madad et al., 2020).

Staff turnover and the reliance on temporary or rotating personnel challenge the maintenance of competency in biocontainment procedures. Studies have demonstrated that PPE donning and doffing skills deteriorate within months of initial training, necessitating frequent refresher sessions that compete with clinical demands (Barratt et al., 2021; Kang et al., 2021). The development of digital training platforms and micro-learning modules may address this challenge by enabling flexible, self-paced competency maintenance (Chen et al., 2021; Singh et al., 2020).

Cultural barriers also impede implementation, particularly regarding the willingness of radiology staff to enter isolation rooms with HCID patients. Concerns about personal safety, compounded by initial shortages of appropriate PPE during the COVID-19 pandemic, led to reluctance among some staff to participate in biocontainment imaging (Belingheri et al., 2021; Shanafelt et al., 2020). Addressing these concerns requires transparent communication about infection control measures, visible leadership commitment to staff safety, and psychological support for staff involved in high-risk procedures (Greenberg et al., 2020; Raudenska et al., 2020).

Future Directions

Looking forward, several areas warrant focused research and development to advance the field of biocontainment imaging. The integration of artificial intelligence (AI) into portable imaging devices holds promise for reducing the need for repeat imaging and enabling remote interpretation without requiring additional personnel in isolation rooms (Awotunde et al., 2021; Lakhani et al., 2020). AI algorithms capable of detecting critical findings on chest radiographs or ultrasound images could alert clinicians to deterioration requiring intervention, potentially reducing the frequency of imaging encounters (Born et al., 2021; Harmon et al., 2020).

Advances in robotics and teleoperation may enable imaging procedures to be performed with minimal direct contact between staff and infected patients. Remotely operated ultrasound systems have been successfully deployed in several settings, though widespread adoption awaits cost reduction and validation in HCID contexts (Adams et al., 2021; Boman et al., 2020). Similarly, the development of self-sanitizing surfaces and antimicrobial coatings for imaging equipment could reduce reliance on chemical disinfection and extend equipment lifespan (Hosseini et al., 2021; Suman et al., 2020).

Standardization of protocols across institutions and healthcare systems would facilitate mutual aid during large-scale outbreaks and enable more robust research on effective practices. Organizations such as the Society of Interventional Radiology and the American College of Radiology have begun developing consensus guidance, but further work is needed to establish widely accepted standards that account for variations in resources and patient populations (Davenport et al., 2020; Prabhakar et al., 2020).

Conclusion

The development and implementation of high-level biocontainment imaging protocols represent a critical component of healthcare system preparedness for emerging infectious diseases. This narrative review has synthesized evidence demonstrating that effective protocols require integration of portable and point-of-care imaging technologies, rigorous nursing protocols for patient management and PPE adherence, pharmacy systems for medication stabilization and waste reduction, administrative structures for risk-based scheduling and documentation, engineering controls for environmental safety, and comprehensive simulation-based education. The absence of standardized protocols represents a significant vulnerability that can result in delayed diagnosis, healthcare worker infections, and erosion of public trust. Moving forward, healthcare institutions must prioritize investment in the infrastructure, equipment, and training necessary to safely image patients with severe communicable diseases, recognizing that the next outbreak may emerge with little warning. The radiology suite, when properly configured as a biocontainment environment, can serve not merely as a diagnostic service but as a model for interdisciplinary readiness in high-acuity, high-consequence situations.

References

1. Abu Awwad, D., Hill, S., Lewis, S., & Jimenez, Y. (2023). Knowledge, attitudes and practice of infection prevention and control in the CT suite. *BMC Health Services Research*, *23*(1), 741. https://doi.org/10.1186/s12913-023-09779-9
2. Awotunde, J. B., Folorunso, S. O., Jimoh, R. G., Adeniyi, E. A., Abiodun, K. M., & Ajamu, G. J. (2021). Application of artificial intelligence for COVID-19 epidemic: an exploratory study, opportunities, challenges, and future prospects. *Artificial intelligence for COVID-19*, 47-61.

https://doi.org/10.1007/978-3-030-69744-0_4

3. Buonsenso, D., & De Rose, C. (2021). Pediatric COVID-19 lung ultrasound. In *Image-Guided Management of COVID-19 Lung Disease* (pp. 51-67). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-66614-9_5
4. Centers for Disease Control and Prevention. (2020, June). *Interim infection prevention and control recommendations for healthcare personnel during the coronavirus disease 2019 (COVID-19) pandemic*.
5. Davenport, M. S., Bruno, M. A., Iyer, R. S., Johnson, A. M., Herrera, R., Nicola, G. N., ... & Weinstein, S. (2020). ACR statement on safe resumption of routine radiology care during the coronavirus disease 2019 (COVID-19) pandemic. *Journal of the American College of Radiology*, *17*(7), 839-844. https://doi.org/10.1016/j.jacr.2020.05.001
6. Dos Santos, T., & de Castro, L. F. (2021). Evaluation of a portable Ultraviolet C (UV-C) device for hospital surface decontamination. *Photodiagnosis and Photodynamic Therapy*, *33*, 102161. https://doi.org/10.1016/j.pdpdt.2020.102161
7. Fischer II, W. A., Uyeki, T. M., & Tauxe, R. V. (2015). Ebola virus disease: What clinicians in the United States need to know. *American journal of infection control*, *43*(8), 788-793. https://doi.org/10.1016/j.ajic.2015.05.005
8. Flinn, J. B., Hynes, N. A., Sauer, L. M., Maragakis, L. L., & Garibaldi, B. T. (2021). The role of dedicated biocontainment patient care units in preparing for COVID-19 and other infectious disease outbreaks. *Infection Control & Hospital Epidemiology*, *42*(2), 208-211. doi:10.1017/ice.2020.451
9. Fregene, T. E., Nadarajah, P., Buckley, J. F., Bigham, S., & Nangalia, V. (2020). Use of in situ simulation to evaluate the operational readiness of a high-consequence infectious disease intensive care unit. *Anaesthesia*, *75*(6), 733-738. https://doi.org/10.1111/anae.15048
10. Gostin, L. O., Ooms, G., Heywood, M., Røttingen, J. A., Haffeld, J., Møgedal, S., ... & Friedman, E. (2010). The joint action and learning initiative on national and global responsibilities for health. *Georgetown Public Law Research Paper*, (10-70). https://ssrn.com/abstract=1714604
11. Herstein, J. J., Wolf, T., Nicastri, E., Leo, Y. S., Lim, P. L., Jacobs, M., ... & Lowe, J. J. (2022). Capabilities of global high-level isolation units: a pre-workshop survey. *Infection Control & Hospital Epidemiology*, *43*(11), 1679-1685. doi:10.1017/ice.2021.477
12. Hick, J. L., Hanfling, D., Wynia, M. K., & Pavia, A. T. (2020). Duty to plan: health care, crisis standards of care, and novel coronavirus SARS-CoV-2. *Nam Perspectives*, *2020*, 10-31478. https://doi.org/10.31478/202003b
13. Hudson, B. J., Loughborough, W. W., Oliver, H. C., Callow, M. E., Pressdee, D. J., Bond, S. J., ... & Phillips, A. J. (2020). Lasting lessons learnt in the radiology department from the battle with COVID-19. *Clinical Radiology*, *75*(8), 586-591. https://doi.org/10.1016/j.crad.2020.06.001
14. Imanipour, M., Ebadi, A., Monadi Ziarat, H., & Mohammadi, M. M. (2022). The effect of competency-based education on clinical performance of health care providers: A systematic review and meta-analysis. *International Journal of Nursing Practice*, *28*(1), e13003. https://doi.org/10.1111/ijn.13003
15. Kanne, J. P., Little, B. P., Chung, J. H., Elicker, B. M., & Ketai, L. H. (2020). Essentials for radiologists on COVID-19: an update—radiology scientific expert panel. *Radiology*, *296*(2), E113-E114. https://doi.org/10.1148/radiol.2020200527
16. Lamontagne, F., Fowler, R. A., Adhikari, N. K., Murthy, S., Brett-Major, D. M., Jacobs, M., ... & Guyatt, G. H. (2018). Evidence-based guidelines for supportive care of patients with Ebola virus disease. *The Lancet*, *391*(10121), 700-708. https://doi.org/10.1016/S0140-6736(17)31795-6
17. Lowe, A. E., Le, A. B., & Gibbs, S. G. (2022). How Should Biocontainment Balance Infection Control With Practice Sustainability?. *AMA Journal of Ethics*, *24*(10), 944-950. doi: 10.1001/amajethics.2022.944.
18. Marrs, R., Horsley, T. L., Hackbarth, D., & Landon, E. (2020). High consequence infectious diseases training using interprofessional simulation and TeamSTEPPS. *American Journal of Infection Control*, *48*(6), 615-620. https://doi.org/10.1016/j.ajic.2019.10.007
19. Mossa-Basha, M., Meltzer, C. C., Kim, D. C., Tuite, M. J., Kolli, K. P., & Tan, B. S. (2020). Radiology department preparedness for COVID-19: radiology scientific expert review panel. *Radiology*, *296*(2), E106-E112. https://doi.org/10.1148/radiol.2020200988
20. Mumma, J. M., Durso, F. T., Casanova, L. M., Erukunuakpor, K., Kraft, C. S., Ray, S. M., ... & Jacob, J. T. (2019). Common

behaviors and faults when doffing personal protective equipment for patients with serious communicable diseases. *Clinical Infectious Diseases*, *69*(Supplement_3), S214-S220. https://doi.org/10.1093/cid/ciz614

21. Niu, Y., Xian, J., Lei, Z., Liu, X., & Sun, Q. (2020). Management of infection control and radiological protection in diagnostic radiology examination of COVID-19 cases. *Radiation medicine and protection*, *1*(02), 75-80. https://doi.org/10.1016/j.radmp.2020.05.005
22. Popescu, S., & Leach, R. (2019). Identifying gaps in frontline healthcare facility high-consequence infectious disease preparedness. *Health security*, *17*(2), 117-123. https://doi.org/10.1089/hs.2018.0098
23. Phan, L. T., Maita, D., Mortiz, D. C., Weber, R., Fritzen-Pedicini, C., Bleasdale, S. C., ... & CDC Prevention Epicenters Program. (2019). Personal protective equipment doffing practices of healthcare workers. *Journal of occupational and environmental hygiene*, *16*(8), 575-581. https://doi.org/10.1080/15459624.2019.1628350
24. Poller, B., Tunbridge, A., Hall, S., Beadsworth, M., Jacobs, M., Peters, E., ... & High Consequence Infectious Diseases Project Working Group. (2018). A unified personal protective equipment ensemble for clinical response to possible high consequence infectious diseases: a consensus document on behalf of the HCID programme. *Journal of Infection*, *77*(6), 496-502. https://doi.org/10.1016/j.jinf.2018.08.016
25. Prabhakar, A. M., Glover IV, M., Schaefer, P. W., & Brink, J. A. (2020). Academic radiology departmental operational strategy related to the coronavirus disease 2019 (COVID-19) pandemic. *Journal of the American college of radiology*, *17*(6), 730-733. https://doi.org/10.1016/j.jacr.2020.04.004
26. Rehani, B., Rodriguez, J. A., Nguyen, J. K., Patel, M. M., Ammanuel, S. G., Winford, E., & Dillon, W. P. (2022). COVID-19 radiology preparedness, challenges & opportunities: responses from 18 countries. *Current problems in diagnostic radiology*, *51*(2), 196-203. https://doi.org/10.1067/j.cpradiol.2021.03.017
27. Rojek, A. M., Dutch, M., Camilleri, D., Gardiner, E., Smith, E., Marshall, C., ... & Putland, M. (2020). Early clinical response to a high consequence infectious disease outbreak: insights from COVID-19. *The Medical Journal of Australia*, *212*(10), 447-450. doi: 10.5694/mja2.50608
28. Rubin, G. D., Ryerson, C. J., Haramati, L. B., Sverzellati, N., Kanne, J. P., Raoof, S., ... & Leung, A. N. (2020). The role of chest imaging in patient management during the COVID-19 pandemic: a multinational consensus statement from the Fleischner Society. *Radiology*, *296*(1), 172-180. https://doi.org/10.1148/radiol.2020201365
29. Rutala, W. A., & Weber, D. J. (2021). Disinfection and sterilization in health care facilities: an overview and current issues. *Infectious Disease Clinics*, *35*(3), 575-607. https://doi.org/10.1016/j.idc.2021.04.004
30. Sánchez, S. M., Shenoy, E. S., & Biddinger, P. D. (2020). The indispensable role of emergency medicine in national preparedness for high consequence infectious diseases (HCIDs). *JACEP Open*, *1*(2), 78-79. https://doi.org/10.1002/emp2.12041
31. Sander, C., Dercks, N. V., Fehrenbach, M. K., Wende, T., Stehr, S., Winkler, D., ... & Arlt, F. (2021). Neurosurgical care during the COVID-19 pandemic in central germany: A retrospective single center study of the second wave. *International Journal of Environmental Research and Public Health*, *18*(22), 12034. https://doi.org/10.3390/ijerph182212034
32. Sebba, D., Lastovich, A. G., Kuroda, M., Fallows, E., Johnson, J., Ahouidi, A., ... & Weidemaier, K. (2018). A point-of-care diagnostic for differentiating Ebola from endemic febrile diseases. *Science translational medicine*, *10*(471), eaat0944. https://doi.org/10.1126/scitranslmed.aat0944
33. Shanafelt, T., Ripp, J., & Trockel, M. (2020). Understanding and addressing sources of anxiety among health care professionals during the COVID-19 pandemic. *Jama*, *323*(21). doi:10.1001/jama.2020.5893
34. Suen, L. K., Guo, Y. P., Tong, D. W., Leung, P. H., Lung, D., Ng, M. S., ... & Yu, W. (2018). Self-contamination during doffing of personal protective equipment by healthcare workers to prevent Ebola transmission. *Antimicrobial Resistance & Infection Control*, *7*(1), 157. https://doi.org/10.1186/s13756-018-0433-y
35. Villarosa, A. R., Ramjan, L. M., Maneze, D., & George, A. (2021). Conducting population health research during the COVID-19 pandemic: impacts and recommendations. *Sustainability*, *13*(6), 3320. https://doi.org/10.3390/su13063320
36. Wang, X. (2021). A retrospective on the intellectual adventures of think tanks in

biosecurity before and after the COVID-19 pandemic outbreak. *Journal of Biosafety and Biosecurity*, *3*(2), 155-162. https://doi.org/10.1016/j.jobb.2021.10.002

37. Westerway, S. C., & Basseal, J. M. (2022). Endocavity ultrasound transducers: why high-level disinfection is necessary. *Ultraschall in der Medizin-European Journal of Ultrasound*, *43*(02), 204-208. DOI: 10.1055/a-1168-6602
38. Whittaker, E., & Sinha, R. (2021). COVID-19: lessons learned from a paediatric high consequence infectious diseases unit. *Archives of disease in childhood*, *106*(4), e20-e20. https://doi.org/10.1136/archdischild-2020-319114
39. Wong, J., Goh, Q. Y., Tan, Z., Lie, S. A., Tay, Y. C., Ng, S. Y., & Soh, C. R. (2020). Preparing for a COVID-19 pandemic: a review of operating room outbreak response measures in a large tertiary hospital in Singapore. *Canadian Journal of Anesthesia/Journal canadien d'anesthésie*, *67*(6), 732-745. https://doi.org/10.1007/s12630-020-01620-9
40. Yassi, A., Zungu, M., Spiegel, J. M., Kistnasamy, B., Lockhart, K., Jones, D., ... & Darwin, L. (2016). Protecting health workers from infectious disease transmission: an exploration of a Canadian-South African partnership of partnerships. *Globalization and health*, *12*(1), 10. https://doi.org/10.1186/s12992-016-0145-0
41. Yeh, K. B., Adams, M., Stamper, P. D., Dasgupta, D., Hewson, R., Buck, C. D., ... & Hay, J. (2016). National laboratory planning: developing sustainable biocontainment laboratories in limited resource areas. *Health security*, *14*(5), 323-330. https://doi.org/10.1089/hs.2015.0079.