Disaster Medicine and Public Health Preparedness

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Research Letters

Cite this article: Dorzweiler P, Schötz K and Döhla M (2026). Testing a Minimal Three-Zone Surgical Setup Under Infrastructure-Degraded Conditions. *Disaster Medicine and Public Health Preparedness*, **20**, e216, 1–3
https://doi.org/10.1017/dmp.2026.10483

Received: 26 May 2026 UTC
Revised: 15 September 2026 UTC
Accepted: 12 October 2026 UTC

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Testing a Minimal Three-Zone Surgical Setup Under Infrastructure-Degraded Conditions

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Abstract

Infrastructure degradation during conflicts and disasters may necessitate temporary surgical capability in improvised environments lacking conventional operating-room infrastructure. We operationally evaluated a minimal 3-zone surgical setup consisting of a contaminated dirty zone (12 m^2), a semiclean transition zone (15 m^2), and a protected procedural core (14 m^2). Workflow simulations demonstrated reproducible separation of patient, personnel, material, and waste flows within a total operational footprint of 41 m^2. Spatial demand was primarily determined by contamination control, workflow separation, and procedural movement geometry.

Armed conflicts, infrastructure attacks, and large-scale disasters increasingly challenge the ability to maintain surgical capability under degraded environmental conditions.[1-3] Under such circumstances, surgical care may need to be temporarily relocated into improvised environments including basements, shelters, tunnels, or other confined spaces lacking conventional operating-room infrastructure.[1,2] Existing surgical and infection prevention guidance is predominantly based on stable health care systems and provides limited operational orientation for highly constrained environments.[3-5]

Pragmatic zoning and workflow-separation strategies may therefore represent a feasible approach for maintaining temporary surgical capability under austere conditions. However, the operational feasibility and spatial implications of such configurations remain poorly explored.

We therefore constructed and operationally evaluated a full-scale minimal three-zone surgical setup under simulated infrastructure-degraded conditions. The objective was not to validate operating-room equivalence, but to explore whether functional zoning and directional workflow separation could support controllable operational organization within a highly constrained spatial configuration.

Methods

A full-scale simulated austere surgical setup was constructed using a 3-zone configuration consisting of a contaminated dirty zone, a semiclean transition zone, and a protected procedural core. The tested minimum configuration comprised 12 m^2 dirty-zone capacity, 15 m^2 semiclean-zone capacity, and a 14 m^2 protected procedural core, resulting in a total operational area of 41 m^2.

The setup was designed to operationalize principles of functional zoning, contamination-flow separation, restricted personnel movement, and directional workflow organization under infrastructure-degraded conditions. The dirty zone functioned as a contamination and material sink for patient reception, removal of contaminated clothing and equipment, temporary waste holding, and gross contamination control. The semiclean zone was intended for staff preparation, clean material staging, medication and device preparation, and stretcher-compatible patient transfer. The protected procedural core prioritized circumferential procedural access and minimized workflow turbulence.

Operational movement simulations and workflow simulations were performed to evaluate functional overlap, movement restriction, transfer compatibility, and congestion effects. Patient, personnel, material, and waste pathways were separately mapped within the setup. During iterative testing, attempted integration of limited medical-device reprocessing into the semiclean zone was additionally assessed regarding spatial compatibility with existing transition-zone functions. Full-scale movement simulations involving stretcher transfer, personnel circulation, material staging, and waste removal were repeatedly performed within the constructed setup.

Spatial demand was not derived from architectural standards but from dominant operational drivers within each zone. Dirty-zone demand was primarily shaped by contamination accumulation and temporary holding requirements. Semiclean-zone demand was determined by the

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need to prevent overlap between storage, preparation, and transfer activities. The protected procedural core was primarily constrained by circumferential procedural movement geometry around the patient.

Results

The tested 3-zone configuration allowed reproducible separation of patient, personnel, material, and waste pathways while preserving a controllable procedural core within a total operational footprint of 41 m^2. Functional zoning substantially improved workflow clarity and reduced direct overlap between contamination-generating and protected activities (Figure 1).

The dominant spatial driver within the dirty zone was contamination accumulation and temporary holding demand associated with patient arrival, contaminated clothing, personal equipment, and waste staging. In the semiclean zone, spatial demand was primarily determined by the need to prevent overlap between clean storage, staff preparation, medication and device preparation, and stretcher-compatible transfer pathways. Reduction of transition-zone area rapidly resulted in corridor obstruction and mixed-use congestion.

The protected procedural core was primarily limited by procedural movement geometry around the patient. Circumferential access requirements for surgical, anesthetic, and support activities substantially restricted further reduction of the procedural area below approximately 14 m^2.

Attempted integration of limited medical-device reprocessing into the semiclean zone produced immediate functional overlap with storage, transfer, and preparation workflows. Reprocessing capability was therefore removed from the tested minimum configuration and operationally reclassified as an optional modular extension requiring additional dedicated space.

Discussion

This study explored the operational feasibility of a minimal three-zone surgical setup under simulated infrastructure-degraded conditions. Rather than attempting replication of hospital-equivalent operating-room infrastructure, the evaluated configuration focused on pragmatic operational organization through functional zoning and workflow separation. The findings suggest that even highly constrained surgical environments may benefit from structured spatial separation concepts when conventional infrastructure becomes unavailable.

Importantly, the tested configuration was not derived from architectural standards or health care construction guidelines. Instead, spatial requirements emerged from dominant operational drivers within each zone. Dirty-zone demand was primarily shaped by contamination accumulation and temporary holding requirements. Semiclean-zone demand was determined by the need to prevent functional overlap between storage, preparation, and transfer activities. In contrast, the protected procedural core was mainly constrained by procedural movement geometry around the patient.

This distinction is operationally relevant because it shifts spatial planning away from purely architectural assumptions toward functional process requirements. The findings additionally suggest that minimum spatial demand in austere surgical environments may not primarily result from equipment volume itself, but rather from the need to preserve separation between competing workflows. Once overlap between transfer pathways, storage areas, preparation surfaces, and contamination sinks occurred, workflow stability rapidly deteriorated. Similar operational concerns regarding movement-associated contamination and workflow instability have previously been described in conventional operating-room environments.[6-8]

The semiclean zone appeared particularly vulnerable to congestion effects because it simultaneously functioned as the principal

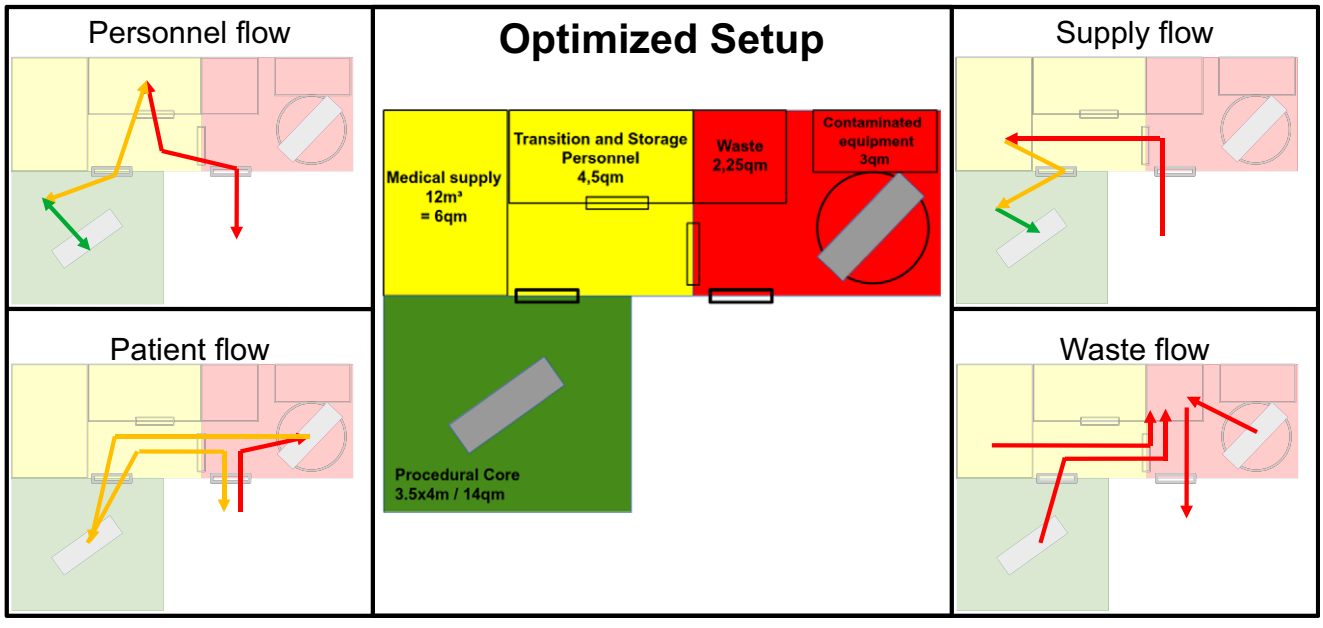


Figure 1. Tested minimum 3-zone surgical setup under simulated infrastructure-degraded conditions. The evaluated configuration consisted of a contaminated dirty zone (12 m^2), a semiclean transition zone (15 m^2), and a protected procedural core (14 m^2), resulting in a total operational footprint of 41 m^2. The setup was designed to support functional zoning and directional workflow separation under austere conditions. Peripheral panels depict separated patient, personnel, material, and waste flows within the setup.

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transition, preparation, and logistical buffer compartment. Attempted integration of medical-device reprocessing into this area immediately generated functional interference with transfer and preparation workflows. This observation supports conceptual distinctions between essential core capabilities and optional modular extensions under degraded operational conditions.

The present study has important limitations. No microbiological sampling, airflow engineering, particulate analysis, or clinical outcome assessment was performed. Consequently, the study does not validate infection prevention effectiveness, operating-room equivalence, or environmental safety. The setup furthermore represents a simulation-based operational evaluation rather than a validated health care design standard.

Nevertheless, the study may provide useful operational orientation for future research into austere surgical environments. The presented configuration should therefore be interpreted as a pragmatically derived reference model rather than a normative minimum standard. Future work should incorporate environmental measurements, airflow characterization, thermal burden analysis, and simulation-based evaluation of prolonged procedural operation under degraded conditions.[9,10]

Acknowledgments. The authors thank Steffen Schuchardt and Sarah Bachmann for their technical support as well as the German Medical Regiment 2 for its logistical support.

Author contributions. Peter Dorzweiler contributed to setup development, operational testing, and drafted the manuscript. Katharina Schötz contributed to workflow evaluation, infection prevention considerations, and manuscript revision. Manuel Döhla conceptualized and supervised the study and critical manuscript revision. All authors reviewed and approved the final manuscript.

Competing interests. None.

Ethical standards. No personal data were collected, processed, or saved for this study. No experiments were conducted on or with humans or animals.

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