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Major Article

Splash generation and droplet dispersal in a well-designed, centralized high-level disinfection unit



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Background: Sterile processing personnel routinely decontaminate medical devices that are heavily soiled with blood, tissue, and secretions. Contamination may spread throughout processing areas, potentially exposing personnel and patient-ready devices, especially when there is insufficient separation between the dirty and clean areas.

Objective: This study aimed to identify activities that generate splash, determine how far droplets travel during manual cleaning, characterize the impact of practices on splash generation, and assess effectiveness of personal protective equipment (PPE) at preventing splash exposure to technicians and visitors in the decontamination unit.

Methods: Moisture-detection paper was affixed to PPE and environmental surfaces in a new processing department designed to optimize workflow and prevent cross-contamination. Droplet generation and dispersal were assessed during manual cleaning of a colonoscope and a transvaginal ultrasound probe.

Results: Splash was generated by most activities and droplets were detected up to 7.25 feet away. Transporting wet endoscopes dispersed droplets on a 15-foot path from the sink to the automated endoscope reprocessor. Extensive droplets were detected on PPE worn by technicians at the sink and observers 3–4 feet away.

Conclusions: Manual cleaning of devices generated substantial splash, drenching technicians and the environment with droplets that traveled more than 7 feet. Engineering controls and better PPE are needed to reduce personnel exposure and risks associated with the potential dispersal of contaminated fluids throughout the facility.

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Sterile processing personnel routinely decontaminate medical devices that are heavily contaminated with blood, tissue, and patient secretions. Recent studies illustrate the potential for contamination from clinically used endoscopes to spread throughout processing areas and expose personnel and processed devices. During a multisite study of

1,709 samples from fully processed duodenoscopes, researchers detected microbes in 65% and high-concern organisms (HCO) in 5%. Environmental sampling detected *Staphylococcus*, *Acinetobacter*, and *Pseudomonas* in processing sinks and on floors, and 63% of the HCO found in these samples were also detected in patient-ready duodenoscopes,¹ suggesting that the environment contaminated the endoscopes or vice versa. In another study, 60% of samples from 20 fully processed duodenoscopes had microbes (55% gram-negative bacteria) and gram-negative bacteria were detected on settle plates near the sampling area in a processing suite.² A 2022 study in a sterile processing unit found that droplets created during manual cleaning and rinsing were dispersed 5 feet (1.5 meters), landing on faucets, irrigation systems, counters, walls, and floors and drenching personal protective equipment (PPE) worn by the technician at the sink.³

Occupational Safety and Health Administration (OSHA) regulations require that PPE be provided to all workers with potential exposure to

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“splashes, spray, spatter, or droplets of blood or other potentially infectious materials.”⁴ PPE should not allow hazards to reach employee clothing, skin, eyes, or mouth.⁴ Standards and guidelines also recommend PPE for personnel in decontamination areas, including eye protection (e.g., goggles or a face-shield); fluid-resistant face masks, shoe covers, and gowns; and extended-cuff gloves.^{5,6} However, according to the National Institute for Occupational Safety and Health (NIOSH), PPE is the least effective rung on their hierarchy of controls for mitigating exposure to occupational hazards.⁷ More durable interventions that are less dependent on individuals are favored to reduce exposure, including changing policies (administrative controls), the built environment (engineering controls), or replacing or removing the hazard entirely (substitution or elimination). Guidelines and standards define the optimal processing environment as a two-room unit with physical separation and unidirectional workflow between dirty and clean activities,⁸ or at least 4 feet (1.2 meters) of separation between the dirty and clean areas in a one-room design.^{5,6}

This study aimed to expand on findings from the previous research³ by identifying processing activities that generate splashes, characterizing splash amount and dispersal patterns in manual cleaning areas, evaluating visitor splash exposure, characterizing the impact of practices and equipment on splash generation, and assessing PPE effectiveness at preventing exposure during routine activities.

METHODS

Setting

This study was conducted in a new sterile processing department of a large urban academic medical center. This unit processes an average of 47 devices per day, including flexible and rigid endoscopes, ultrasound probes, light cords, and camera heads that require high-level disinfection (HLD) or low-

temperature gas sterilization. This unit was chosen because it has a three-room design intended to optimize processing outcomes while meeting built-environment guidelines and reducing the risk of cross-contamination (Fig 1A).

The decontamination area (10.5 × 18.25 feet [3.2 × 5.6 meters]) is separated from the automated endoscope reprocessor (AER) loading area (10.5 × 21.75 feet [3.2 × 6.6 meters]) by a wall with an open doorway. After manual cleaning, ultrasound probes and other devices are brought to a separate room (10.5 × 20.6 feet [3.2 × 6.3 meters]) for HLD (Tropon 2, Nanosonics; New South Wales, Australia) or sterilization (Sterrad 100NX, Advanced Sterilization Products; Irvine, CA).

The manual cleaning area has two ergonomic workstations with adjustable-height counters, dual-basin sinks (Getinge; Gothenberg, Sweden), and other processing equipment. Endoscopes are manually cleaned in one basin and transferred to another for rinsing in a transport cassette with AER channel connections (Advantage Hookup Cassettes, Cantel Medical Corporation; Little Falls, NJ). The AERs (Advantage Passthrough, Medivators; Minneapolis, Minnesota) are embedded into a wall separating the dirty side of the suite from the clean side. After HLD, endoscopes are removed from the AER on the clean side (8.5 × 65.8 feet [2.5 × 20 meters]), placed in drying cabinets, and stored before transport to clinics. The processing suite was designed to ensure that the decontamination area has negative air pressure compared to all surrounding rooms and the clean side has positive air pressure compared to all surrounding rooms.

Moisture detection methods

Researchers used duct tape to affix large sheets of blue moisture-detection paper (ScopeDry Check, Healthmark Industries; Fraser, Michigan) to environmental surfaces, including the floor, floor mats, counters, walls, leak tester, and irrigation system. In

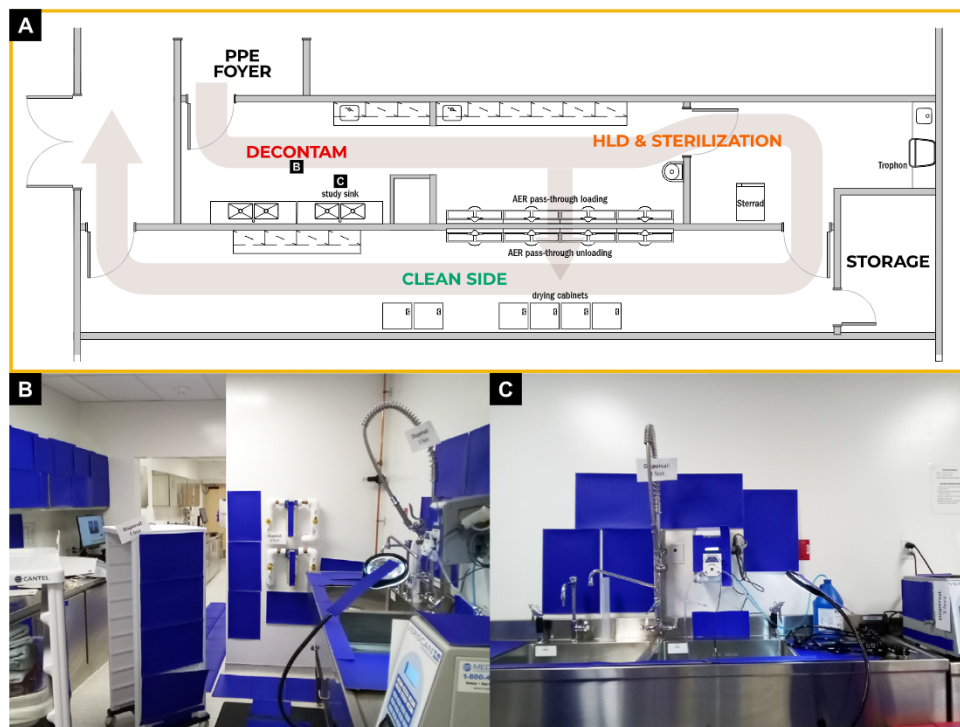


Fig 1. Study site set-up. A) Layout of a three-room centralized HLD unit (locations of images in 1B-C indicated by letter); B) Decontamination sink with blue moisture detection paper, carts to simulate observers, and distance labels; C) Straight view of sink set-up and blue moisture detection paper.

addition, moisture-detection paper was attached to carts positioned 4 feet (1.2 meters) away from the sink (Fig 1B-C). The paths from the sink to the AERs and the sink to the door of the suite were paved with moisture-detection paper to evaluate droplet dispersal from wet endoscope transport cassettes and shoe covers. Labels indicating distance from the sink were affixed to surfaces to facilitate documentation of droplet dispersal. Strips of moisture-detection paper were also affixed to PPE worn by researchers during simulated manual cleaning activities.

Droplet generation and dispersal were documented via photographs taken with a tablet camera (Tab M8HD, Lenovo; Quarry Bay, Hong Kong), observations by researchers, and verbal reports from technicians standing within the splash zone. Two independent researchers counted droplets visible in photos of moisture-detection paper adhered to PPE and environmental surfaces. The endpoints were droplet generation, droplet dispersal, and PPE exposure and effectiveness for the technician at the sink and other nearby personnel.

Instruments and processing activities

The study measured splash and droplet dispersal during simulated processing activities performed by experienced, certified processing professionals in a terminally disinfected decontamination area to minimize personnel exposure. These activities included manual cleaning of a decommissioned colonoscope (EC-530HL2, Fujifilm; Tokyo, Japan) and transvaginal ultrasound probe (RIC-5-9A-RS, General Electric; Boston, Massachusetts) used exclusively for training purposes.

Droplet dispersal was evaluated during colonoscope brushing and scrubbing with a channel brush (WB7025DC, Fujifilm; Tokyo, Japan), toothbrush (DawnMist soft, Donovan Industries; Tampa, Florida) and sponge (Dry Sponge, Healthmark; Fraser, Michigan), rinsing, and transport in a cassette designed to be loaded into the AER. For the probe, droplet dispersal was evaluated during brushing, scrubbing, and rinsing when partially immersed according to manufacturer instructions for use (IFU). Droplet spread was also assessed while filling the sink and walking to the decontamination room door after cleaning one device. To evaluate the impact of sink height on splash generation, experiments were done with the sink at a comfortable height for the technician and when it was 4 inches too high. Experiments also assessed the impact of brushing and scrubbing while devices were fully or partially submerged.

PPE exposure and effectiveness

Per departmental policies and available supplies, PPE included shoe covers (Anti-skid polypropylene shoe covers, Cardinal Health; Dublin, Ireland), gowns (Aero Blue AAMI Level 3 & 4 Surgical Gown, Halyard Health; Alpharetta, Georgia), gloves (Sterling Nitrile Exam Glove; Purple Nitrile XTRA Exam Glove, Halyard

Health), face shields with drop-down splash guard (Full Face Shield, Key Surgical; Eden Prairie, Minnesota), face masks (Fluidshield, Halyard Health), and headcovers (Tri-Layer Bouffant Cap, Halyard Health).

PPE exposure was evaluated on the technician at the sink and observers standing at the adjacent sink and 3-4 feet away. PPE components were evaluated for effectiveness, including the face shield with the splashguard, shoe covers, gowns, and double gloving with gloves that were properly sized or with outer gloves that were too large. Moisture-detection paper was affixed inside gloves and shoe covers to assess fluid incursion.

RESULTS

Splash generation and dispersal during simulated cleaning

Splash was generated by almost every manual cleaning activity evaluated (Table 1). Activities that involved running the faucet were associated with the substantial splashing (Fig 2A-B). Rinsing the probe per IFU (two minutes under running water)⁹ generated more small droplets, large droplets, and confluent puddles of water around the sink than any other activity (Fig 2C-E).

Droplets were detected on counters, walls, a wall-mounted water filtration system, an irrigation system, a magnifying glass, a leak tester, floors, and carts. Upon completing manual cleaning activities for the colonoscope and probe, multiple droplets were recorded between 4 and 6 feet (1.2–1.8 meters) from the decontamination sink. Droplets from rinsing the probe were observed on the floor 7.25 feet (2.2 meters) away. Transport of a wet endoscope and cassette between the sink and AER generated droplets that were visible on the entire path (>15 feet; 4.6 m) (Fig 2F-H).

Minimal to no splash was created when the endoscope and probe were brushed and scrubbed while submerged per IFU while the sink was positioned at a comfortable height for the technician. When cleaning was performed with the sink approximately 4 inches higher than comfortable, technicians reported difficulty completing tasks and slightly more splash. Brushing and scrubbing with the devices above the surface significantly increased splash generation (e.g., increase from 26 droplets to TNTC on the counter), regardless of sink height, and droplets were observed on the wall 6 feet (1.8 meters) away.

PPE exposure and effectiveness

The technician at the sink was exposed to droplets from head to toe during most activities (Table 1). During high-splash activities like probe rinsing, confluent splash patterns and droplets TNTC were observed on gowns and shoe covers (Fig 3A-C). Face shields and the extended chin cover were frequently exposed to substantial splash (Fig 3D). In some cases, large numbers of droplets were visible on the gown around the moisture-detection

Table 1
Averaged droplet counts on moisture-detection paper affixed to PPE and environmental surfaces by activity from two independent researchers

Activity	Environment			Tech at sink (PPE)			Observer at 3–4 feet (PPE)		
	Counter	Wall	Floor	Gown	Face shield	Shoe covers	Gown	Face shield	Shoe covers
Filling the sink	TNTC	175	99	108	1	3	0	0	0
Cleaning sink with spray arm	TNTC	88	78	90	9	21	3	0	1
Cleaning endoscope	26	1	6	4	0	0	0	0	0
Cleaning probe	0	0	0	0	0	0	0	0	0
Rinsing endoscope	TNTC	50	233	TNTC	12	10	0	0	0
Rinsing probe	TNTC	TNTC	TNTC	TNTC	9	TNTC	58	0	12
Transporting scope to AER	-	-	TNTC	-	-	1	-	-	-

Abbreviations: TNTC (too numerous to count; 300+ droplets); – (not applicable; no data collected)



Fig 2. Workstation exposure to droplets during decontamination activities.

paper that were not reflected in the droplet counts in Table 1 (Fig 3E). The technician noted that despite heavy splash exposure, the gown effectively repelled the moisture for the duration of the experiment (cleaning one device). No fluid incursion was observed when the technician wore properly sized gloves. Fluid incursion was observed on the interior glove when exterior gloves were too large (Fig 3F).

Extensive droplets were detected on gowns and shoe covers of observers at an adjacent sink (Fig 3G; Table 1). Observers standing 3 to 4 feet (0.9-1.2 meters) away were also exposed to

droplets (Fig 3H). More observer exposure occurred during the probe rinsing than other activities (Table 1). Numerous droplets were observed on a cart 4 feet (1.2 meters) away during probe rinsing, including several droplets at least 42 inches (1.1 meters) off the ground (Fig 3I). During brushing when the endoscope was incompletely submerged, an observer standing 3 feet (0.9 meters) away reported droplets spraying past their head, but no droplets were visible on the moisture-detection paper. Despite wearing a head cover, this observer also felt droplets on top of their head (i. e., skin exposure). A subsequent attempt to document droplet



Fig 3. PPE exposure to droplets generated during probe decontamination activities.

incursion through the headcover was inconclusive as only 2 small droplets were detected on moisture-detection paper inside headcovers.

Shoe covers were heavily exposed to droplets and puddles, particularly those created during probe decontamination (Fig 4A–B). Moisture-detection paper placed inside a shoe cover showed fluid incursion through the shoe cover from the top (Fig 4C) and through the seam along the bottom (Fig 4D). Saturated shoe covers tracked moisture from the decontamination sink to the unit door, 13 feet (4 meters) away, and out into the PPE foyer (2 feet/0.6 meters further) (Fig 4E–F).

DISCUSSION

Key findings and implications

In this study, droplets were generated and dispersed by most decontamination activities, including filling the sink, cleaning a colonoscope and transvaginal ultrasound probe, transporting the endoscope between the sink and AER, and walking to the unit door. Some activities, particularly rinsing the probe per IFU, generated substantial splash that heavily exposed the environment and equipment near the sink, the technician at the sink, and observers and vertical

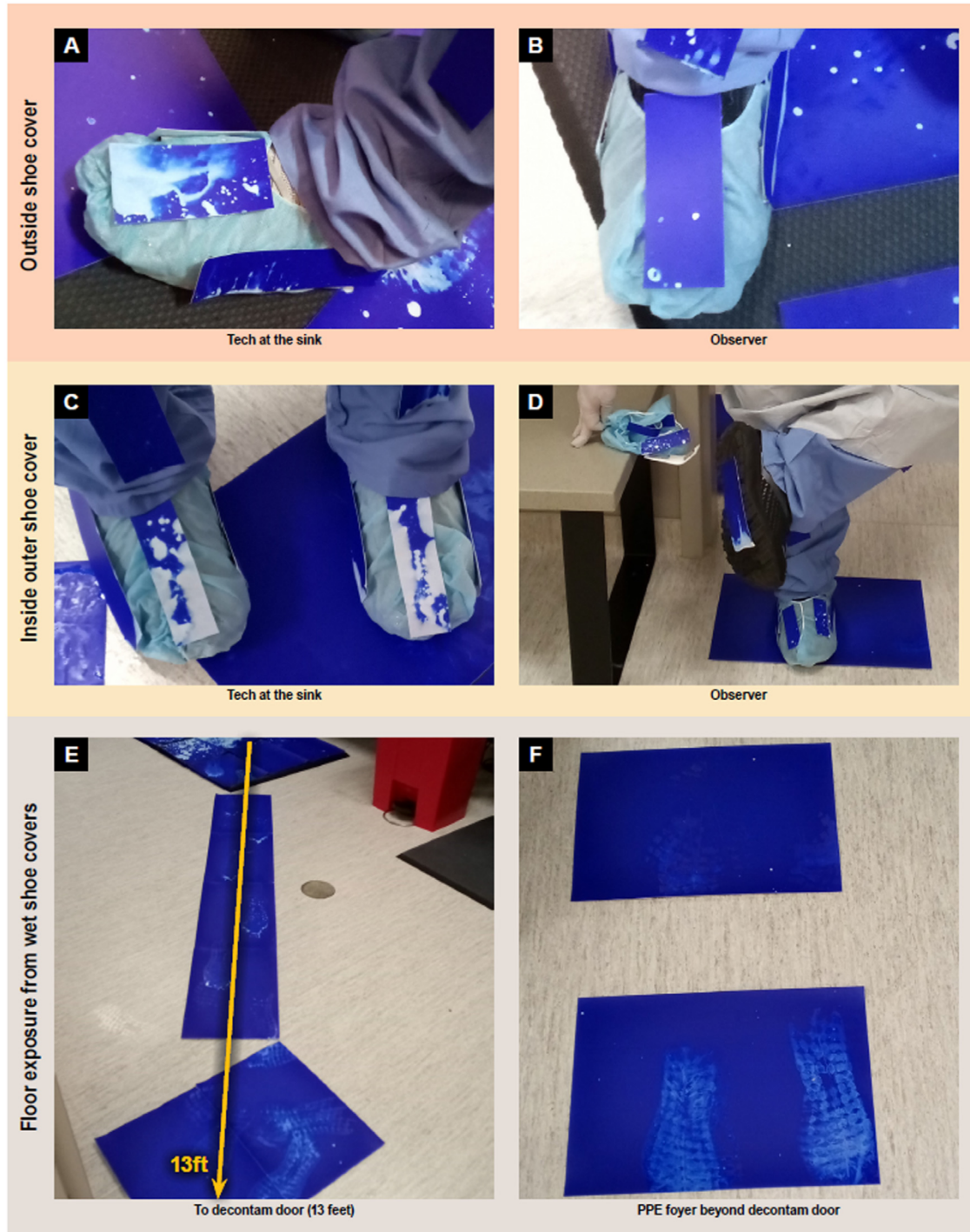


Fig 4. Fluid incursion in shoe covers and subsequent moisture tracking throughout decontamination unit.

surfaces 4–6 feet (1.2–1.8 meters) away. Droplets were documented up to 7.2 feet (2.2 meters) from the sink. Guidelines currently recommend a 3–4 foot (0.9–1.2 meters) separation between dirty and clean areas. Although the splashes exposed the technician and nearby observers, droplets did not reach areas where fully processed devices are handled and stored due to the unit layout.

The technician at the sink was drenched head-to-toe during manual cleaning and observers 3–4 feet (0.9–1.2 meters) away were also exposed. Notably, droplet counts in [Table 1](#) reflect only one cycle of each activity. The unit processes an average of 47 devices daily, and a technician commonly processes 4–5 endoscopes or 8–10 probes

during a 2-hour work block. As a result, their PPE is subjected to high volumes of fluid for extended periods of time. This is concerning as researchers have found that soaking exposure was more likely to leak through gowns than spraying exposure.¹⁰ Standards state that “liquids can act as a vehicle for the transfer of microorganisms” and wet PPE should be considered contaminated,⁵ which raises questions about the safest methods for doffing. Recently, researchers investigated self-contamination risks when reusing PPE due to COVID-19 supply issues.¹¹ They found that 100% of HCW performing mock patient care activities contaminated their face, neck, and/or hands. Such clinicians arguably have far less exposure than personnel

working in device decontamination units. These findings, combined with PPE fluid exposure observed in the current study, emphasize the need for training on safely removing PPE and highlight the risk of reusing PPE in the decontamination area. Although standards state that attire should be changed whenever wet or visibly contaminated, current practices do not involve frequent PPE or attire changes by personnel working in decontamination areas.⁵

Several studies have documented other implications of splashes in healthcare settings. Multiple outbreaks have been linked to contamination disseminated from sinks.^{12–16} In one outbreak, 36 patients were infected with *Pseudomonas aeruginosa* from contaminated hand hygiene sinks. Investigators determined that droplets traveled at least 1 meter from the sink, exposing prep areas to the pathogen.¹³ The outbreak was terminated by placing barriers around the sink, moving prep areas further away, and reducing splash by changing the faucet design and lowering water pressure. Other researchers reported that fully processed duodenoscopes harbored HCOs that were also detected on floors and sinks in processing areas, raising the possibility of cross contamination.¹

In the current study, puddles formed on floor mats near the sink, and droplets were dispersed when transporting colonoscopes to the AER. The shoe covers of technicians and observers were saturated and tracked moisture throughout the unit and outside the door. These findings suggest that there is potential for personnel foot exposure and for dispersing contamination from the processing unit to other areas of the healthcare facility. A recent study detected COVID-19 genetic material on in-patient pharmacy floors, and researchers concluded that contaminated shoes and attire of HCWs carried it there from patient-care areas.¹⁷

Solutions and the hierarchy of controls

NIOSH, industry standards, and professional guidelines call for elimination of hazards where possible, instead of relying on PPE to protect workers.^{5,7,18} This could be accomplished with single-use devices that do not require processing, or closed systems that contain and automate manual cleaning. Alternatively, devices could be redesigned to reduce the risks and burdens of manual cleaning (e.g., probes that do not require rinsing under running water; transport cassettes that do not drip). When elimination is not an option, engineering and administrative controls should be implemented to mitigate exposure risk as much as possible before relying on PPE.^{5,7,18} Infection preventionists play a critical role in relaying this evidence to stakeholders in other departments, including sterile processing managers and supervisors.

Engineering controls include a spectrum of potential solutions. This could include lowering water pressure or installing tubing on faucets to direct the flow and reduce splash generated during activities like rinsing ultrasound probes under the running water. Ergonomic workstations and sink designs that create less splash could reduce risks of bacteria aerosolization when running faucets, as found with air sampling during an outbreak investigation.¹⁵ For sites able to consider new construction, separating the unit into multiple rooms, increasing the square footage to allow for more separation, and incorporating barriers could help reduce splash exposure.

Administrative controls include policy-based strategies for reducing risk, such as immersing devices whenever possible during cleaning and stepping back from the sink during filling.³ Policies should reflect recommendations to restrict traffic and require anyone entering the unit to wear full PPE.⁵ To meet the needs of diverse staff, managers should fit-test all employees to ensure that properly sized gowns, gloves, masks, and shoe covers are available. Training programs should teach technicians how to properly use and doff PPE,^{5,18} and compliance should be monitored.

Finally, while PPE should not be the first and only line of defense against occupational hazards, it should still be as effective as possible. PPE used by processing personnel should cover multiple hazards, including potential exposure to bloodborne pathogens, other infectious or biological materials, and water and chemicals used during cleaning, HLD, and sterilization. Fluid-resistant PPE for the decontamination unit should be available in sizes to fit the diverse workforce so that no skin, mucous membranes, or shoes are exposed. Ideally, PPE should be comfortable, or at least tolerable enough to support proper use. Supply chain issues and PPE quality problems have placed sterile processing workers at risk, and improvements in PPE features and quality are needed.

Limitations

This study was conducted after hours at a single site with a well-designed processing unit. These findings may not be generalizable because highly experienced, certified managers performed single cycles of simulated manual cleaning. Droplet dispersal relied on counts from photographs of moisture-detection paper, which underrepresented splash observed by researchers and did not include aerosols.

CONCLUSIONS

In this study, substantial splashes were generated and droplets were dispersed more than 7 feet (2.1 meters) during the manual cleaning of a colonoscope and an ultrasound probe. This exposed the environment, technicians, and observers, whether or not they were at the sink. More research on clinical implications of droplet dispersal in the processing unit is needed and should include risk of exposure to biological and chemical hazards. Innovative solutions for splash reduction should prioritize worker health and patient safety and involve stakeholders including guideline-issuing bodies, vendors, infection preventionists, sterile processing managers, and frontline technicians.

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