

Research Paper

Feasibility and acceptability of a novel intervention to improve hand hygiene behavior in rural Liberian health facilities

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ABSTRACT

Hand hygiene is central to the prevention of healthcare-associated infection. In low-income settings, barriers to health worker hand hygiene may include inconsistent availability of hand hygiene supplies at the point of care. However, there is a lack of knowledge of interventions to improve and sustain health worker hand hygiene in these settings. This pilot study evaluates acceptability and feasibility of a personally-worn hand hygiene holster device for improving point-of-care access to alcohol-based handrub (ABHR). Holsters were distributed to clinical staff at a hospital in Liberia in July–September 2021. Data collection included 2,066 structured observations of hand hygiene behavior, six spot checks of supply availability, and focus group discussions with 13 clinical staff. The Integrated Behavioral Model for Water, Sanitation, and Hygiene (IBM-WASH) provided a framework for study design and qualitative analysis. Acceptability of the intervention was high, with users reporting that holsters were comfortable, easy to use, and aligned with their professional identities. Feasibility depended on consistent ABHR availability, which may diminish sustainability of this intervention. The hand hygiene holster is a promising tool for improving health worker hand hygiene behavior, but solutions to ABHR supply chain and distribution constraints are necessary to support sustainability of this intervention.

Key words: behavior change, hand hygiene, infection prevention, Liberia, pilot study

HIGHLIGHTS

- This pilot study evaluated the feasibility and acceptability of a hand hygiene holster device to improve access to point-of-care hand hygiene in Liberian health facilities.
- Users reported satisfaction with holsters and many felt that this intervention made hand hygiene more accessible during patient care.
- Further research should explore the impact of the holster intervention on health worker hand hygiene behavior.

INTRODUCTION

Poor hand hygiene contributes to the spread of infectious disease in healthcare environments (Burke 2003). The burden of healthcare-associated infection is particularly high in low- and middle-income countries (LMICs), with an estimated prevalence of 15.5 infections per 100 patients in these settings (Allegranzi *et al.* 2011). In the healthcare setting, non-compliance with hand hygiene protocol may occur at the individual level when health workers are not motivated to wash hands or do not perceive hand hygiene to be important (Pittet 2000; Sethi *et al.* 2012). Non-compliance may also arise from institutional-level factors when hand hygiene materials and infrastructure are unavailable or placed at inconvenient locations (Sethi *et al.* 2012; Ataiyero *et al.* 2019).

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Hand hygiene guidelines emphasize the importance of convenient access to alcohol-based handrub (ABHR) or handwashing facilities at the point of care, where health workers come into contact with patients and their surroundings (WHO 2009). Interventions to provide point-of-care access to ABHR have been associated with time saved for health workers in comparison to soap and water usage, improvements in hand hygiene compliance, and reductions in healthcare-associated infection (Pittet 2000; Hugonnet *et al.* 2002; Kendall *et al.* 2012). Visual cues can act as a reminder for hand hygiene, and hand hygiene stations that are easily accessible and highly visible at the point of care are particularly effective in facilitating hand hygiene (Nevo *et al.* 2010; Ford *et al.* 2014; Cure & Van Enk 2015).

In spite of the importance of hand hygiene in healthcare settings, health facilities in LMIC settings often lack hand hygiene at the point of care: In a 2020 assessment, 70% of health facilities in sub-Saharan Africa had handwashing stations with soap and water at points of care, 43% had ABHR at the point of care, and 27% had no hand hygiene available at the point of care (WHO 2020). An evaluation of hand hygiene at seven rural Liberian hospitals found that 23% of hospital wards reportedly always had access to piped running water, 89% to water in bucket containers, and 62% to soap, while 8% of wards and 70% of bathrooms had no hand hygiene material available (Tantum *et al.* 2021). Furthermore, hand hygiene stations may be located at a distance from patient bedsides, making them inconvenient to use during patient care and unable to serve as visual cues (Pittet 2000).

Individual-level distribution of ABHR is a potentially effective strategy for supporting access to hand hygiene at the point of care, particularly in settings where other hand hygiene stations are difficult to access. Issuance of pocket-size ABHR bottles to health workers has been associated with improved hand hygiene compliance in health facilities in Uganda and Switzerland (Hugonnet *et al.* 2002; Saito *et al.* 2017). Wearable devices to carry and dispense ABHR have been introduced in high-income health facility settings and, in some cases, have been associated with improved health worker hand hygiene and reduced incidence of infection (Haas & Larson 2008; Koff *et al.* 2011; Keller *et al.* 2018). However, these interventions faced barriers to acceptability and sustainability as users were dissatisfied with designs (Keller *et al.* 2018) and did not use devices consistently over time (Haas & Larson 2008; Koff *et al.* 2011).

Hand hygiene interventions are most sustainable when they support the formation of new habits. Behaviors become habitual when they are performed automatically, in response to an environmental cue (Verplanken 2006). In addition to routines and cues, hand hygiene may be motivated by factors such as disgust sensitivity and fear of personal infection (Curtis *et al.* 2009). Environmental determinants, availability of supplies and infrastructure, and social norms around hand hygiene also influence behavior (Curtis *et al.* 2009). The design and physical character of intervention materials – including their ease of use, comfort, and perceived value – also plays a role in acceptability and habit formation (Devine 2010). Sustainability is an important consideration in hand hygiene intervention design, as interventions can promote behavior change and foster a culture of hand hygiene by generating a stable, predictable environment where habits can form (Verplanken 2006; Curtis *et al.* 2009). However, hand hygiene intervention sustainability in LMIC health facilities is difficult to achieve, particularly in settings that lack the finances, supply chain capacity, and administrative oversight to maintain interventions without outside support (Holmen *et al.* 2016; Loftus *et al.* 2019).

The aim of this study was to perform a pilot evaluation of a hand hygiene holster, a wearable device containing a pump-style ABHR dispenser, in a rural Liberian health facility. This device was designed to make hand hygiene easily accessible at the point of care and overcome barriers related to the availability and positioning of hospital hand hygiene infrastructure. To address supply-related constraints to hand hygiene, holster implementation was accompanied by low-cost production of ABHR at the health facility. This study addresses gaps in knowledge of interventions that could be feasible and sustainable for improving health worker hand hygiene in LMICs. We hypothesized that holsters, in combination with a reliable supply of ABHR, could support and sustain behavior change by improving point-of-care accessibility to hand hygiene and by serving as a visual cue to clean hands.

METHODS

Study design

This was the second phase of a three-phase project to improve hospital hand hygiene in Liberia. Phase 1 consisted of a baseline hand hygiene assessment (Tantum *et al.* 2021). Phase 2, described in this paper, involved a pilot to understand feasibility and acceptability of a hand hygiene intervention in advance of full-scale implementation (Van Teijlingen & Hundley 2002). The third phase will involve implementation and evaluation of interventions across four Liberian health facilities.

Study design and evaluation drew from the Integrated Behavioral Model for Water, Sanitation, and Hygiene (IBM-WASH) and by conceptual and methodological frameworks for pilot studies. IBM-WASH provides a framework for evaluating determinants of water, sanitation, and hygiene behavior. The model places factors influencing behavior into three dimensions – technology, psychosocial, and contextual – each of which acts at five levels: societal/structural, community, interpersonal, individual, and habitual (Dreibelbis *et al.* 2013). IBM-WASH has informed the design and piloting of household WASH interventions in community settings (Hulland *et al.* 2013; Hussain *et al.* 2017; Yeasmin *et al.* 2017). We adapted the IBM-WASH framework for use in the healthcare setting, including by conceptualizing the ‘community’ level as encompassing the hospital environment and culture (Supplementary Table S1). We drew from established approaches for pilot studies to obtain in-depth feedback on the intervention from participants (Van Teijlingen & Hundley 2002; Malmqvist *et al.* 2019).

Hand hygiene holster intervention design

In a baseline evaluation of hand hygiene in Liberian health facilities, healthcare workers expressed preference for using individually carried ABHR devices for hand hygiene (Tantum *et al.* 2021). Our pilot intervention was a hand hygiene holster, a wearable device for accessing ABHR at the point of care. The holster concept originated with medical personnel in the Bangladesh Armed Forces, who anecdotally reported increased hand hygiene compliance when wearing the devices (Styczynski, 2020). The holsters used in this study were designed and manufactured in Bangladesh by Lidia May Ltd. Holsters include a pocket for a 230 mL pump-style ABHR bottle, another pocket to hold a cell phone, and adjustable waist and shoulder straps. They are made of durable material that can be machine-washed or wiped clean with alcohol solution (Figure 1).

In addition, we implemented hospital-based production of ABHR, supported by study funds, to provide a supply of material for filling holster bottles. We purchased all ABHR production materials and equipment in Monrovia, Liberia. In collaboration with hospital administration, we identified a production site within the facility and trained pharmacy and infection control staff in production following WHO guidelines (WHO 2010). Three rounds of ABHR production took place during the



Figure 1 | Hand hygiene holster, 2022 (Images courtesy of Adam Gsellman).

pilot, with each round yielding 10–20 liters of ABHR. We anticipated that this would be a sufficient quantity to fill holster bottles and other dispensers in the hospital during the pilot period.

Study site and population

We implemented and evaluated the pilot intervention at a hospital in rural Bong County, Liberia in July–September 2021. Bong County experienced a large Ebola outbreak, including 26 Ebola cases and 7 deaths among health workers, during the 2014–16 Ebola virus disease epidemic (Lori *et al.* 2015). In a baseline evaluation completed in spring 2020, the hospital had 150 beds and 40 total clinical staff. The hospital had access to generator power. Water was available year-round from a nearby hand pump, but piped water was unavailable within the hospital. All clinical staff at the hospital, as well as non-clinical staff who interacted with patients, received the holster intervention. Focus group discussions employed a convenience sampling approach. We selected staff who were present at the facility and had time and willingness to participate in a focus group discussion.

Pilot structure

In this pilot, we distributed 47 holsters to all full-time clinical staff in the facility – including all nurses, nurse aides, and doctors – as well as pharmacy and immunization staff. We initially planned that holsters would be shared between staff on different shifts. However, in the days following initial implementation, we learned that staff strongly preferred exclusive access to their holster due to perceived hygiene issues with sharing. We then supplied each staff member with their own holster. Holsters were intended to be stored in hospital offices or storage spaces when not in-use, but the majority of staff members took their holsters home with them at the end of their shift. Staff were individually responsible for cleaning their holsters, while infection control personnel monitored the system and performed additional cleaning as necessary.

ABHR was stored in the hospital pharmacy, as this location was supervised and accessible during all working hours. Staff visited the pharmacy when they needed to refill the ABHR bottle in their holster. To differentiate the impact of ABHR production alone versus ABHR with holsters, we introduced ABHR production and distributed ABHR to communal bottles on hospital wards 2 weeks prior to holster distribution.

A research team visited the hospital every 2 weeks for 3 days to perform structured observations of hand hygiene behavior and spot check evaluations of hand hygiene material availability. Spot checks and structured observations contributed to an understanding of intervention uptake and usage behavior among staff. The team performed six rounds of evaluation, including three rounds of evaluation prior to implementation of any interventions, one round where ABHR production had begun but holsters were not yet introduced, and two rounds after introduction of holsters (Figure 2). Six weeks after introduction of holsters, we held focus group discussions with hospital staff who had received holsters. Focus group discussion guides were derived from the IBM-WASH framework (Supplementary Table S1).

Data collection

Data collection included structured observations of hand hygiene behavior during clinical care, spot checks of hand hygiene supplies and infrastructure, and focus group discussions. During structured observations, enumerators observed health workers during patient care and recorded hand hygiene behavior at five key clinical moments in accordance with WHO guidelines (WHO 2009). In total, observers recorded 2,066 hand hygiene moments. At each observed moment, enumerators recorded whether the health worker performed hand hygiene on hands; applied ABHR to gloves; changed gloves only; or performed no hand hygiene. Enumerators also evaluated whether the health worker used ABHR or soap and water for hand hygiene and, if they used ABHR, whether the source was a holster or a different type of dispenser.

Enumerators collected data on hospital hand hygiene supplies and infrastructure, including water, soap, and ABHR, during six spot check surveys. Enumerators also assessed availability and condition (excellent/like new; good, i.e. somewhat worn; poor, i.e. usable but heavily worn; or broken/not usable) of each holster to evaluate durability of the devices. Enumerators recorded all quantitative data using Open Data Kit software. Debriefs with enumerators during and after the study provided an opportunity to adjust and improve upon tools in advance of their use in the planned full intervention.

Through two focus group discussions with a total of 13 hospital staff members, qualitative researchers gathered staff perspectives on the hand hygiene holster intervention. Each discussion took place within the hospital and lasted approximately 45 min to 1 h. Focus group guides included questions related to satisfaction with holsters and determinants of holster usage.

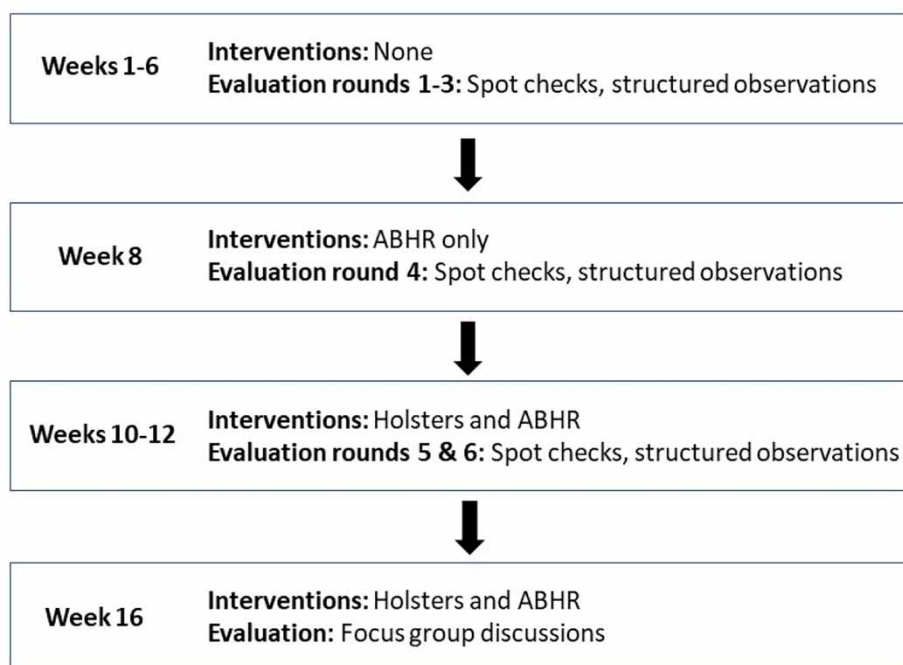


Figure 2 | Timeline of piloting and data collection for hand hygiene holster intervention.

Data analysis

We used structured observation data to evaluate changes over time in hand hygiene behavior, use of ABHR versus soap for hand hygiene, and use of holsters for hand hygiene. We calculated the overall proportion of observed moments where staff performed hand hygiene, the proportion of hand hygiene actions where staff used ABHR versus soap and water, and the proportion of moments where a holster was used as the ABHR source (WHO 2009). To perform statistical analysis, we used z -tests for two population proportions with significance levels set at $\alpha = 0.05$ to compare differences in the proportion of staff performing hand hygiene at observed moments and the proportion using ABHR for hand hygiene pre- and post-intervention.

Using spot check data, we generated descriptive statistics to evaluate the proportion of holsters present on hospital wards or in storage and the proportion reported as being in good or excellent condition during two data collection visits. We also evaluated availability of other hand hygiene sources, including sink stations, water bucket dispenser stations, hand soap, and ABHR dispensers on wards.

To perform thematic analysis of focus group discussions, we created a codebook with theory-driven codes derived from the IBM-WASH framework and adapted for the hospital setting and pilot study context (DeCuir-Gunby *et al.* 2011; Dreibelbis *et al.* 2013). To establish reliability of the codebook, two researchers coded focus group discussions separately, then compared codes to identify differences in interpretation and reach a consensus. Qualitative data analysis centered around the factors at each level and dimension of IBM-WASH that facilitated or impeded feasibility and acceptability of the intervention.

Ethics

Focus group discussion participants engaged in a written informed consent process that included explanation of the study purpose, their anonymity, audio-recording, and their ability to leave the discussion at any time. Enumerators did not record identifying information during observations. Data from discussions, observations, and spot checks were de-identified to prevent identification of individual participants. Enumerators uploaded electronic data to a secure server and did not save data on their devices. Study methods were reviewed and approved by the National Research Ethics Board of Liberia (protocol NREB-003-21) and the Stanford University IRB (protocol CGHE-B1-9011).

RESULTS

Spot check results

During six spot checks, researchers evaluated availability of hand hygiene materials on hospital wards, including running water in sinks, water in bucket dispensers, hand soap, and ABHR. During evaluations conducted prior to intervention implementation, 45–70% of wards had water available in bucket dispensers and 18–40% had at least one source of ABHR available. After implementation of both the ABHR production and holster interventions, 75–100% of wards had bucket water available and 86–88% had at least one source of ABHR available, aside from holsters (Supplementary Figure S1).

Field researchers evaluated holster availability and condition during post-intervention spot checks. During spot checks, 32–43% of holsters were present at the facility for evaluation, as many staff had taken their holsters home on their days off. All available holsters contained bottles and 90–100% were deemed to be in excellent or like-new condition (Supplementary Table S3).

Structured observation results

Enumerators observed health worker hand hygiene behavior and usage of ABHR during patient care across six evaluation rounds before and after locally produced ABHR and holsters were introduced (Supplementary Figure S2). In total, enumerators observed 2,066 hand hygiene moments across all rounds. Staff used ABHR for 57% of hand hygiene actions observed after the introduction of the holster intervention, compared to 17% of moments when no interventions were available ($p < 0.001$) and 36% of moments when only the ABHR production intervention was available ($p = 0.001$). Overall hand hygiene compliance, which included usage of soap and ABHR for hand hygiene, increased to 68% during the evaluation conducted after introduction of the ABHR production intervention, compared to observed compliance levels of 48% pre-intervention and 49% after introduction of the holster intervention ($p < 0.001$). Differences in observed hand hygiene compliance pre-intervention and after the introduction of the holster intervention did not reach statistical significance ($p = 0.772$) (Supplementary Table S5).

Focus group discussion results

Staff provided feedback on the intervention during two focus group discussions. Participants in Focus Group 1 included nine nurses, while participants in Focus Group 2 were one nurse supervisor, one midwife, one infection control focal person, and one pharmacist. Focus group discussion themes corresponded to the three dimensions of IBM-WASH: technology, psychosocial, and contextual dimensions (Dreibelbis *et al.* 2013; Table 1).

Technology dimension

At the habitual level, participants described hand hygiene holsters as comfortable and convenient for routine use: ‘It is not heavy, it’s not a burden, it’s not occupying space that you are working in... It’s easy to carry’. Four participants linked the holster to hand hygiene habit formation, explaining that the device acted as a physical and visual reminder to perform hand hygiene: ‘It’s on me, and each time I feel it, I know that it’s there for hand hygiene’. Some participants also noted that the portable nature of the holster facilitated hand hygiene behavior. Several felt that the holster saved time compared to other hand hygiene sources, particularly soap and water: ‘Sometimes you may have many patients in the ER to attend to. The time it will take me to go and wash my hands and come back, I can easily access my hand sanitizer which is in the holster’.

Participants shared feedback on physical attributes and perceived quality of the holster device at the individual level. Participants liked the design of holsters, with three specifying that they liked the addition of a pocket for a cell phone. Some suggested modifications to the holster design, including adding pockets for pens or cash and offering the holster in other colors: ‘Maybe I will want to come to work maybe with a black holster, or I will want to come with the white one matching in my white uniform’. Some participants said that the holsters did not fit well on larger individuals and suggested elongating the straps to fit a wider range of body types. Participants felt that holsters were durable and high-quality. Of the 12 participants who commented on durability, 1 felt the holster would last 3–6 months; 2 felt it would last 6 months to 1 year; 6 felt it would last 1–2 years; and 3 felt it would last for more than 2 years.

Health worker preference for holsters over shared hand hygiene materials operated at the interpersonal level. Eleven participants expressed a preference for individual-based distribution and maintenance of holsters, rather than a system where they shared holsters with staff on other shifts. Some explained that they were worried that other staff might neglect to clean the holster or might misplace it. Having one’s own holster, rather than sharing hand hygiene materials with other

Table 1 | Participant viewpoints and sample quotes corresponding with IBM-WASH levels and dimensions (Dreibelbis *et al.* 2013) from focus group discussions with intervention users at Liberian hospital, 2021

Dimension	Level	Participant viewpoint	Sample quote
Technology	Habitual	Holsters serve as a physical reminder to perform hand hygiene	'Once it's hanging on you, you are reminded always. If you even touch something that you are not supposed to touch, it will remind you to wash your hands'. – Group 2, R3
	Individual	Holsters are comfortable to wear and convenient to use	'It is very easy, and comfortable to work with. You can work with it and move it anywhere'. – Group 2, R4
	Interpersonal	Prefer individual over shared devices	'Some people will misuse it... it is preferred that you alone have it'. – Group 1, R3
	Community	Sometimes had difficulty accessing ABHR	'My alcohol is finished... When we went for refilling, they said it's not on hand'. – Group 2, R1
	Societal	Would be willing to purchase holsters	'I can pay \$10 for this'. – Group 1, R1
Psychosocial	Habitual	Holsters are easy to use and helpful for hand hygiene	'Anytime you think about touching patients you think about using it'. – Group 1, R9
	Individual	Holster usage supports infection prevention	'It will prevent us from getting infected'. – Group 1, R5
	Interpersonal	Holster design supports health worker identity	'The beauty about it is that it's just one of its kind, and the first of its kind in Liberia'. – Group 2, R4
	Community	Hand hygiene protects patients and wider community	'It also helps my family when I am going home. It helps to save them'. – Group 1, R6
	Societal	Interest in labeling holster with medical logos	'Because we are in a clinical setting, so we will use the rod with the snake'. – Group 2, R4
Contextual	Habitual	Consistent availability of materials supports hand hygiene	'Once the material is available, it makes me feel happy to [do] the work'. – Group 2, R2
	Individual	Holster usage determined by staff role or ward	'Sometimes when I am finished with procedures, my hands will be soiled'. – Group 2, R2
	Interpersonal	Most hand hygiene materials shared among all staff	'So for our department, we usually used yellow soap. We put the soap there and just use it to wash our hands'. – Group 2, R1
	Community	ABHR more efficient and convenient than handwashing	'The more you got the patients, the more you use the sanitizers'. – Group 1, R9
	Societal	Hospital-provided hand hygiene supplies available inconsistently	'If there is no money, there will be no hand sanitizers'. – Group 1, R1

staff, afforded participants more control over their health: 'The advantage here is that I can't get any infection from any other person'. Preference for individual control over holsters drove some staff to take their holsters home with them. Two participants said they were worried about someone else using or taking the device if they left it behind at the hospital.

Participants reported following the pilot study protocol of wearing their holster during every workday, with none reporting non-compliance with the holster usage protocol. Most participants said they were always able to refill their holster bottles with ABHR when needed: 'I was on duty when my hand sanitizer was finished. So I hurriedly rushed on the [Obstetrics] Ward and asked for alcohol'. However, five reported that they sometimes had trouble accessing ABHR when they needed it, with some saying that they faced time constraints to visiting ABHR storage locations during the workday. Apart from hospital-provided materials, one participant reported purchasing their own ABHR to refill their holster bottle, and two others reported filling their bottle with chlorine solution.

Operating at the societal/structural level was participant willingness to purchase holsters. Ten participants said that they would be willing to pay for holsters if the devices were available on the market. Of the participants who commented on willingness to pay, two said they would be willing to pay LRD\$500 (approximately US\$3.25); three reported being willing to pay US\$5; four US\$10; and one US\$20-\$25.

Psychosocial dimension

At the habitual level, participants felt that the holster was feasible for routine use. They said it reminded them to perform hand hygiene and helped to encourage hand hygiene habits: 'Now, there is no excuse. It's always on us and it is easily accessible... as you are working, you are using your holster. It can remind us'.

Participants said that holsters were helpful for performing hand hygiene and protecting oneself from infection at the individual level. The portable nature of holsters meant that participants could perform hand hygiene in any location. This was important as many participants perceived infection risks as present throughout the hospital, not just in patient care settings: 'Every hour, every day, minute, you are interacting with a virus'.

At the interpersonal level, several participants described the holsters as a source of pride and a professional symbol, enhancing a culture of hand hygiene at the facility. The novelty of holsters was appealing to some, with one participant describing the holster device as 'the first of its kind in Liberia'. As all clinical staff received holsters, the devices were highly visible throughout the facility: 'I see everybody now carrying it... it's just unique'. However, the distinctiveness of the holster also contributed to frustration among non-clinical staff at the hospital who did not receive the devices. Some participants expressed concern that all staff were at heightened risk of infection when some did not have holsters: 'If one person is infected, it can affect everybody'.

Motivation for hand hygiene and holster usage also emerged at the community level, as participants felt that hand hygiene could protect the health of patients, family members, and others in and out of the hospital setting. Patients noticed and commented on holsters. Two participants said that patients told them their holsters looked like army uniforms: 'When [patients] see these things, they say, are you people army? We say no, we are not soldiers, but we are soldiers for the disease'. Several said that they had explained the importance of hand hygiene to patients who asked about the holster.

Integration of the holster with health systems and leadership operated at the societal/structural level. Some participants were interested in using holsters to highlight their role as health workers and government employees. Five suggested decorating the holster with colors or symbols of the hospital, the medical profession, the local county, and/or the Ministry of Health: 'The people in Bong County should have a specific color. People in Lofa [County] a specific color, based on maybe the geographical flag of the county'.

Contextual dimension

At the habitual level, participants reported that their hand hygiene habits arose from having consistent access to hand hygiene materials on wards and seeing visual reminders for hand hygiene: 'Those materials that are needed for hand washing, when they are available, when you see them, they motivate you. But when they are not available sometimes, you can't be moved to wash your hands'.

Individual-level staff roles and ward placements determined feasibility of holster usage. Staff preferred to use soap and water for hand hygiene when working in areas where they were exposed to blood or other bodily fluids: 'The place that I am assigned is the [Obstetrics] ward, and that ward is a bloody area... I definitely have to wash my hands properly'. In areas where exposure risk was lower, participants said that using holsters and ABHR was sufficient for hand hygiene.

Aside from holsters, hand hygiene materials provided by the hospital were typically shared among all staff on a ward, but several staff reported that they sometimes purchased personal ABHR dispensers for use at work when hospital-provided materials were unavailable: 'We used to receive [ABHR] from the administration, but later we ourselves had to bring them for our own safety'.

The health facility built environment influenced holster usage behavior at the level of the hospital community. In some instances, handwashing stations were located in hallways or offices rather than on wards, posing a barrier to efficient hand hygiene during patient care. Participants said they preferred to use holsters when handwashing stations were not easily accessible: '[The holster] makes me to do my work easily because I can't leave from the patients' room to go the handwashing bucket to go wash my hands and come back'.

At the structural level, participants cited hospital-wide availability of hand hygiene supplies as a major determinant of hand hygiene behavior: '[If] soap is not there you are not really satisfied whether your hands are clean. So the equipment that we need at the washing hand site, if they are available can also motivate us in washing our hands'. However, many reported that, prior to implementation of the intervention, ABHR was provided inconsistently by the hospital. Staff used soap and water for all hand hygiene needs when ABHR was unavailable.

DISCUSSION

This pilot study employed the IBM-WASH framework to evaluate the acceptability and feasibility of a hand hygiene holster device at a hospital in rural Bong County, Liberia. Findings from focus group discussions, spot checks, and structured observations suggest that hand hygiene holsters are feasible for use during clinical care and acceptable to staff at Liberian health

facilities. Focus group discussion participants perceived holster technology to be high-quality and valuable to their professional identity as health workers. They derived motivation to use and maintain holsters from psychosocial factors such as fear of infection. Despite high acceptance of holsters among hospital staff, usage was constrained by contextual factors, as staff were unable to use holsters if ABHR was not available. Furthermore, the intervention did not include a mechanism for enforcing staff usage of holsters during the workday, indicating that protocols and oversight around holster usage require additional consideration.

While focus group participants felt that holsters were useful for improving hand hygiene, we did not observe a significant change in overall hand hygiene compliance during structured observations conducted after implementation of the holster intervention. Structured observations did not distinguish between individuals wearing and not wearing holsters, and holster wearing was not strictly enforced, although all focus group participants self-reported wearing their holster. A more rigorous comparison of holster wearers to non-wearers would strengthen our understanding of the impact of the intervention on behavior. That said, positive qualitative feedback and improved usage of ABHR among holster users indicate that this intervention merits further study. Focus group participants reported using holsters when other hand hygiene sources were difficult to access or located at a distance, highlighting the value of a portable hand hygiene device compared to installation of a fixed station.

Findings from this pilot study have implications for policies and programs to improve healthcare worker hand hygiene in LMICs. Availability of ABHR posed a contextual barrier to feasibility of the pilot intervention. Though 87% of wards had a source of ABHR available in spot checks after intervention implementation, we did not assess whether availability was sustained over time. Focus group participants reported difficulties accessing ABHR prior to, and in some instances during, the intervention, reflecting hand hygiene supply constraints found in many LMIC healthcare settings (Cronk & Bartram 2018). Routine supply provisions for health facilities could include individually distributed ABHR, leveraging the high acceptability for this material among healthcare workers.

Policies to enhance hospital access to ABHR and support local ABHR production could play a role in improving and sustaining hand hygiene in Liberian health facilities. Ethanol and plastic pump bottles, both important components in ABHR production, are not currently produced in Liberia at a quality or price point that is suitable for hospital use (Jacquieroz Bausch *et al.* 2018). Importation of chemical ingredients and dispenser bottles for ABHR production carries expensive shipping and customs costs and poses logistical challenges for health facilities in LMICs (Bauer-Savage *et al.* 2013). An alternative is to build local manufacturing capacity for ethanol alcohol and plastic bottles, following the model of initiatives established in other settings (Ohimain *et al.* 2012; Saraya 2019).

Holsters and bottles used in this study were manufactured in Bangladesh, with holsters costing US\$13.00 to manufacture, and pump bottles \$0.80. As Liberia had 9,661 doctors, nurses, and midwives as of 2018, supplying all medical personnel with holsters and bottles would cost approximately \$134,000 (WHO 2018a, 2018b). Financial costs and logistical considerations associated with shipping holsters and bottles from Bangladesh to Liberia posed an obstacle to hospitals' ability to access this intervention without outside assistance. Efforts to produce holsters at scale or enable local production in Liberia could make this device more affordable and accessible to potential buyers.

Health workers expressed motivation to use holsters due in part to a fear of infection and a desire for self-protection. Self-protection from infection has been reported as a key motivator for hand hygiene among health workers in other worldwide settings (Jang *et al.* 2010; Alex-Hart & Opara 2011; Smiddy *et al.* 2015). Fear of infection and a desire for self-protection also contributed to participant preference for individual control of holsters, with several participants saying they were worried about cross-contamination from a shared device. Holsters may have also enhanced health worker self-efficacy, defined as confidence in one's ability to perform a behavior and produce an intended outcome (Bandura 1977; Janz & Becker 1984; Mendes *et al.* 2020). In the healthcare setting, access to hand hygiene materials may support self-efficacy, contributing to better adherence to hand hygiene guidelines (Cabana *et al.* 1999; Sax *et al.* 2007; Neri *et al.* 2022). The holster intervention could support hand hygiene behavior change by strengthening perceptions of self-efficacy, as the device allows users to control their own access to point-of-care hand hygiene source. Future implementation of hand hygiene holsters should account for health worker preferences to individually control their devices, and should measure the impact of this intervention on hand hygiene behavior.

This study is subject to limitations. The hospital selected for the pilot intervention may not be representative of the context and resource constraints of other rural health facilities in Liberia. The intervention may require adaptation to improve acceptability in other settings. This pilot was intended to analyze feasibility and acceptability of holsters, and therefore was not

designed or powered to evaluate the effectiveness of holsters in improving hand hygiene behavior, the long-term sustainability and durability of holsters, or sustainability of hospital-based ABHR production. Our data collection methods are also subject to limitations. Individuals may alter their behavior while under observation by a research team, meaning that observed adherence to the intervention and hand hygiene protocol may be higher than actual adherence (Holden 2001; Ram *et al.* 2010). A convenience sampling approach was used to select individuals for participation in focus group discussions. The individuals who were available and willing to participate in the discussion may not have been representative of the viewpoints and experiences of all hospital staff. During focus group discussions, discussion participants may provide answers that they feel to be socially desirable, including by overstatement of hand hygiene adherence or reluctance to criticize the intervention, and we did not have a direct measurement of holster adherence. The focus group discussion facilitator encouraged participants to speak freely, and the facilitator was not involved in the distribution of holsters to hospital staff.

CONCLUSIONS

Results from this pilot study indicate that hand hygiene holsters are a feasible tool for supporting hand hygiene improvement in low-resource health facility settings, although more work is needed to develop protocols for holster distribution and storage, promote consistent availability of ABHR, and encourage sustainability of the intervention. Scaled-up distribution of holsters could be accomplished by integrating holsters and ABHR into local markets for individuals or facilities to purchase, though purchasing power in LMICs may be weak. Alternatively, holsters could be provided to health workers through collaboration with central government or non-profit organizations. Integration of holsters and ABHR production into the national infection control budgets and agendas would be a promising path to delivering these interventions at scale. Investigation into the economic impact of holsters and ABHR production, in terms of improved hospital safety and decreased healthcare-associated infection, would provide a case for investment in these interventions. Further research should establish the impact of holsters on hand hygiene behavior and examine the long-term cost-effectiveness and viability of this intervention.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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