RESEARCH ARTICLE

The art and science of achieving zero COVID-19 transmissions in staff at a large community care facility in Singapore using implementation science: a retrospective analysis [version 1; peer review: 1 approved]

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Abstract

Background: The Singapore COVID-19 multi-ministry taskforce commissioned community care facilities (CCFs) as a hospital-sparing strategy amidst rising coronavirus disease 2019 (COVID-19) cases. An exhibition centre was repurposed within ten days as an ad-hoc 3200-bed medical facility (CCF@EXPO) to isolate and treat infected patients amidst concerns of potential COVID-19 transmissions to healthcare staff. This paper deconstructs the implementation of the CCF@EXPO infection prevention and control (IPC) innovation and elicits critical factors which enabled zero transmission of COVID-19 to staff during 100 days of operation using an implementation science framework.

Methods: This study employed retrospective analysis using the integrated Promoting Action on Research Implementation in Health Services (i-PARIHS) framework. The CCF@EXPO IPC innovation comprised five key elements: (a) physical environment, (b) work practices, (c) tools and technology, (d) staff training, and (e) audits. Contextual assessment was conducted for baseline and 100th day of CCF@EXPO operations. Actions taken to improve scores between these timepoints were mapped against the Expert Recommendations for Implementing Change (ERIC) tool to surface key implementation strategies.

Results: Positive shifts were observed in all constructs of the i-PARIHS framework, between baseline and 100th day. The largest shifts were in

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work practices, tools and technology, and staff training. Key implementation strategies used included: rapid Plan-Do-Study-Act (PDSA) cycles, identifying champions, team building, creating a culture of collaborative learning, multi-disciplinary teamwork, transparency in communications and decision-making, and skillful facilitation.

Conclusions: Rapid PDSA cycles anchored by principles to ensure staff safety, was the key approach used in implementation of the CCF@EXPO IPC innovation. Retrospective analysis using the i-PARIHS framework is useful to elicit success factors and to inform preparedness planning of future pandemics.

Keywords

COVID-19, implementation science, infection control, safety management, pandemics, i-PARIHS.

This article is included in the **Pathogens** gateway.

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This article is included in the **Coronavirus** collection.

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Introduction

Many countries have repurposed pre-existing public venues or infrastructure as community care facilities (CCFs) to provide treatment for those infected with coronavirus disease 2019 (COVID-19), reserving hospital care for patients with serious sequelae.¹⁻³ An inherent challenge in using non-healthcare public venues, is to ensure adaptations to layout, infrastructure, workflows, and work practices are designed to support infection prevention and control (IPC) for staff and patient safety. Reports of frontline healthcare professionals who contracted COVID-19 and lost their lives, shock and sadden.⁴⁻⁸ Although no official worldwide tally is available, conservative estimates are that between 7,000 to >20,000 healthcare professionals have died in the line of duty, as of October 2020.^{9,10}

In Singapore, two waves of imported and community cases of COVID-19 in March/April 2020 were dwarfed by a sharp rise in the number of infected migrant workers housed in dormitories.¹¹ The COVID-19 multi-ministry taskforce commissioned CCFs to be rapidly set-up as a hospital-sparing strategy in April 2020 amidst rising cases, to provide care for patients with mild symptoms.¹² Given fatalities in healthcare professionals reported around the world due to COVID-19, ensuring staff safety in CCFs was a priority. We were tasked to set-up a CCF within ten days, repurposing halls in an exhibition centre (hereafter CCF@EXPO) to isolate and treat infected patients in the community.¹³ However, due to the speed required in setting up CCFs, a prospective theory-informed approach to implementation is uncommon. At the time of writing, we found no published studies using implementation science to plan, set-up, and operate a large-scale CCF in this pandemic.

We achieved our goal of zero transmission of COVID-19 to healthcare and non-healthcare staff working at CCF@EXPO, while providing high quality patient care. This paper is a retrospective analysis using implementation science to elicit critical factors in the achievement of the stated goal, and to inform similar endeavors in the future.¹⁴ Contextual barriers and implementation strategies used to address these are surfaced. Findings are reported in line with the Standards for Reporting Implementation Studies (StaRI) checklist.¹⁵

Methods

Ethical approval

Research ethics approval was provided by the SingHealth Centralized Institutional Review Board (CIRB), approval number 2020/2890. Participant consent was waived by the institutional review board.

Study context and contextual challenges

The setting for this paper is the CCF@EXPO (Halls 7 to 10; 3200 beds) run by SingHealth, a major provider of public healthcare in Singapore.¹⁶ The CCF@EXPO comprised ten exhibition halls with a total capacity of 7873 beds, the largest CCF here (extended data file 1³¹).

We highlight the most significant contextual challenges in setting up and managing the SingHealth CCF@EXPO, notwithstanding the ten-day lead time. At the organisational level, SingHealth was stretched in supporting other COVID-19 initiatives e.g. mass swabbing/testing and medical outposts at migrant worker dormitories with COVID-19 clusters.¹⁷ There was no existing blueprint for the set-up and management of large *ad hoc* medical facilities such as CCFs.

Infrastructure adaptations were constrained by both the built environment and time. Critical infrastructural decisions made to enable good IPC practices include layout and workflow, areas for donning/doffing of personal protective equipment (PPE), negative air pressure for patient areas, and additional rest areas for staff to ensure safe distancing within teams and segregation between teams, prior to commencement of operations. There were challenges in rapidly building a resilient well-functioning team. Healthcare staff deployed to CCF@EXPO were from different institutions, diverse disciplines and specialties, and had not functioned as a team previously. Few had expertise in managing COVID-19 patients. There was a significant reduction in staff to patient ratio compared to pre-COVID-19 times.¹³ The need to engage with multiple external vendors/partners (e.g. bed and facility management, cleaning and security services) including training non-healthcare staff in PPE use, introduced added complexity. Patients at CCF@EXPO were mostly male migrant workers from South Asia, who spoke little or no English.

Definitions

The intervention

We defined the intervention as ‘the isolation and treatment of COVID-19 patients not requiring hospital care, in a community care facility’, shown to be effective for virus containment elsewhere¹⁻³ and part of a comprehensive strategy for pandemic management in Singapore.¹²

The Innovation

The innovation is a bundle of five elements focussed on IPC, hereafter referred to as the ‘CCF@EXPO IPC innovation’: (a) physical environment, (b) work practices, (c) tools and technology, (d) staff training, and (e) audits.

i-PARIHS framework

We used the integrated Promoting Action on Research Implementation in Health Services (i-PARIHS) as the framework for retrospective analysis. The i-PARIHS was selected for its real-world applicability to complex interventions which are multi-dimensional, iteratively implemented, and contextual; and for its emphasis on facilitation.^{18,19} Main constructs of the framework are: (a) characteristics of the innovation (the bundle of five elements described above), (b) recipients—the people affected by and who influence implementation (staff at CCF@EXPO), (c) inner context—local (CCF@EXPO), (d) inner context—organisational (SingHealth), (e) outer context (Ministry of Health/National level), and (f) facilitation—the role of facilitators and process of facilitation.¹⁸ Facilitation was led by two facilitators (WEC and HKT) appointed as joint medical directors for the SingHealth CCF@EXPO.

Study design

This was a retrospective case study investigating the end-to-end planning, set-up, operation, and stand-down of the SingHealth CCF@EXPO IPC innovation within a 100-day period from 23rd April to 31st July 2020, which achieved zero transmission of COVID-19 to healthcare and non-healthcare staff.

Patient involvement

Patients were not involved in the design and conduct of this retrospective analysis.

Quantifying implementation

We developed an assessment rubric based on the i-PARIHS framework for a systematic retrospective deconstruction of the CCF@EXPO IPC innovation (EL, WEC).^{18,19} We adapted the i-PARIHS assessment questions into statements accompanied by a qualitative rubric for allocating scores (extended data file 2³¹). The constructs assessed were those described in the preceding section (Definitions: the innovation and i-PARIHS framework). Face validity of the assessment rubric was ascertained (AT, NT, SLC, HKT) and the rubric revised (extended data file 2³¹). Items were scored from 0 to 3. Higher scores (2 or 3) are desirable/signal fewer challenges, while lower scores (0 or 1) are undesirable/signal more challenges. Scores were allocated for baseline (commencement of operations) and 100th day, or pragmatically as close as possible to these two time points constrained by the availability of data.

Assessments were independently completed by three assessors (AT, NT, SLC) representing meso, micro, and arms-length perspectives, respectively. Routine data and resources collected during the 100-day operation of CCF@EXPO were used for assessments: (a) anonymous staff surveys at various timepoints regarding any concerns and feedback pertaining to IPC or being deployed/working at CCF@EXPO (includes responses from the digital Kaizen board, Padlet (an online noticeboard), and pre-deployment survey), (b) IPC audit data (e.g. compliance with use of PPE, hand hygiene, environmental cleaning, food safety, waste management, etc.), (c) a comprehensive matrix summarizing key elements of the innovation (extended data file 3³¹), and (d) on-site observations (AT, NT). As staff surveys and feedback were ongoing during 100 days of CCF@EXPO operations, we primarily used data from the pre-deployment survey (response rate 57%, 56/98) as baseline, and the end-of-deployment survey in the final month of operations. Fifty responses were received for the end-of-deployment survey; a response rate was not calculated as the survey was open to all staff ever deployed within the 100-day period, via word-of-mouth and through posters displayed on-site for those still deployed. In total, there were 488 staff ever deployed to CCF@EXPO in the stated period. Similarly, as IPC audits were conducted daily, data from the first fortnight (baseline) and from the last week of operations were used for assessment (100th day).

Discordant scores for baseline and 100th day were resolved via discussion. Where discordance remained, an average score was used for that item. Scores for items under each sub-construct were averaged and represented as radar diagrams, to serve as visual summaries of the gaps/barriers and strengths/enablers of the innovation (baseline) and any shifts following the use of various implementation strategies (100th day).

Eliciting implementation strategies

We mapped actions taken by facilitators to address contextual barriers at pre-commencement/baseline and iteratively throughout the implementation against the Expert Recommendations for Implementing Change (ERIC), a compilation of 73 discrete implementation strategies, to enable systematic reporting of strategies used.²⁰

Statistical analysis

Descriptive statistics summarised assessment scores for (a) characteristics of the innovation (the bundle of five elements), (b) recipients—the people affected by and who influence implementation (staff at CCF@EXPO), (c) inner context—local (CCF@EXPO), (d) inner context—organisational (SingHealth), and (e) outer context (Ministry of Health/National level). Assessment scores were analysed using [Microsoft Excel](#) (version 2101, build 13628.20448).

Results

The assessments were conducted by three of the authors (AT, NT, SLC).³¹ Baseline scores for *innovation characteristics* indicated that ‘physical environment’, ‘work practices’, ‘tools and technology’, and ‘staff training’ needed to be addressed from an IPC perspective ([Figure 1a](#) and extended data file 4³¹). The main pre-commencement/baseline challenges were ([Table 1](#)): inadequate facilities for PPE donning/doffing and inadequate space for staff to rest/have meal breaks (physical environment); hospital IPC workflows and practices required modifications to suit CCF@EXPO (work practices); missed opportunities to reduce dwell time in patient areas (suboptimal use of tools and technology); and training especially for non-healthcare staff in PPE use,²¹ safe workflows, and safe behaviours (staff training). At baseline, only basic IPC audits were in place.

Several key implementation strategies were used to address baseline challenges for innovation characteristics ([Table 1](#)), driven by Deming’s Plan-Do-Study-Act (PDSA) methodology.²² For example, Plan—assessing local needs for safer work practices (PPE donning/doffing, [Figure 2](#)); Do—developing enhanced practices (conduct training in the use and sequence of PPE donning/doffing, provide gowning stations, posters as visual reminders); Study—audit and feedback (PPE donning/doffing audit, ‘PPE buddy’ (staff were assigned a staff ‘buddy’ for verification of correct donning/doffing of PPE), mirrors); and Act to refine work practices further (trial of Smart mirror). The practice of using posters as a checklist was normalized. A no-blame culture of continual learning and looking out for one another was modelled and encouraged by facilitators and leaders. By the 100th day, PPE compliance had improved from 97% to 100% and from 93% to 98%, respectively, for healthcare and non-healthcare staff. These outcomes were more favourable when compared to another Singaporean study in a hospital setting.²³ Assessments showed positive shifts in all five elements of innovation characteristics by the 100th day.

For *recipients*, baseline scores although favourable ([Figure 1b](#) and extended data file 4³¹), could be strengthened given the challenge of caring for >3000 COVID-19 patients with lean human resources.¹³ The ability to change at the individual level remained stable between the two timepoints—individual staff understood the modifications in workflows and practices for delivery of patient care, and each had the ability, resources (e.g. PPE supplies), and support to enact these workflows and practices. However, positive shifts in scores from baseline to 100th day were observed for motivation to change at individual level, motivation to change at team level, and ability to change at team level.

Key implementation strategies ([Table 1](#)) used to strengthen individual and team efficacy include: facilitators being skillful in identifying champions and domain leads, team building, and creating virtuous cycles centred on cultures of collaborative learning, multi-disciplinary teamwork, as well as transparency in communications and decision-making. Key strategies were enacted mainly through rapid PDSA cycles serving as vehicle and enabler of staff initiatives to improve processes, to identify and raise relevant issues impacting staff safety and patient care, as well as to develop, test, refine and own the solutions. Experiencing themselves as empowered agents of change individually and collectively was critical for rapid ground-up innovation in a pandemic. In the end, increased efficacy and agency of individuals and teams allowed out-of-box thinking beyond comfort zones. New tools and technologies, accompanied by new procedures/protocols refined via PDSA cycles, were adopted as routine work practices. For example, an autonomous robot (TEMI[®], New York, USA) was used to provide medication counselling and tele-triage to reduce staff dwell time in patient areas, and fluorescent marker (Glo-Germ) was used for objective assessment of environmental cleaning during audits ([Figure 3](#)).

Baseline scores for *context* were favourable ([Figure 1c](#) and extended data file 4³¹), which signaled good alignment between culture, leadership, systems, policies, and strategic priorities at local, organisational, and national levels in Singapore. To maintain alignment, facilitators used implementation strategies such as identifying champions at various levels, engaging with executive/advisory boards (for clinical governance, resource allocation, accountability reporting), and developing partnerships (for CCF@EXPO operations or research). Favourable scores for context were maintained at the 100th day ([Figure 1c](#) and extended data file 4³¹).

Facilitation featured strongly as an implementation strategy that ensured success. The findings of the assessment indicate that these are seasoned/expert facilitators (extended data file 5³¹). Facilitators used various communication techniques and channels (formal and informal means) to engage, involve, inform, update, encourage, acknowledge, gather support,

Figure 1. Baseline vs. 100th Day scores for Characteristics of the Innovation, Recipients, and Context.

Table 1. Key implementation strategies used to address contextual barriers identified.

i-PARIHS constructs	Main contextual barriers for infection prevention and control ^a	Key ERIC Implementation strategies used [ERIC list number] ^b
Characteristics of the Innovation		
Physical environment	Inadequate area for PPE donning/doffing (pre-commencement). Inadequate space for staff rest and meal breaks to allow segregation between teams and safe distancing within teams (pre-commencement).	Assess for readiness and identify barriers and facilitators [4], Tailor strategies [63], Visit other sites [72], Change physical infrastructure and equipment [11], Facilitation [33]. ³⁰
Work practices	Hospital IPC work practices not applicable/ required modifications to be suitable for this site. Not all work practices were clearly documented. Safe workflows required. Safe behaviours required.	Conduct local needs assessment [18], Conduct cyclical small tests of change [14], Audit and provide feedback [5], ³⁰ Promote adaptability [51], Identify and prepare champions [35], Visit other sites [72], Facilitation [33]. ³⁰
Tools and technology	Suboptimal use of tools and technology to enhance staff safety by reducing dwell time of staff in 'hot zones' (patient areas), improve workflow, and increase efficiency in provision of care.	Conduct local needs assessment [18], Conduct cyclical small tests of change [14], Identify and prepare champions [35], Tailor strategies [63], Promote adaptability [51], Audit and provide feedback [5], ³⁰ Provide local technical assistance [54], ³⁰ Centralised technical assistance [8], Facilitation [33]. ³⁰
Staff training	Non-healthcare staff required training in correct use of PPE, safe workflows, and safe behaviours. Healthcare staff required similar training/refresher training to meet site requirements. Staff rotations and impact on training. Staff acceptability of myriad new systems, processes, protocols, practices, and policies. Only a fire contingency plan was in place. Other contingency plans pertinent to this site are required.	Conduct local needs assessment [18], Audit and provide feedback [5], ³⁰ Conduct cyclical small tests of change [14], Conduct ongoing training [19], Develop educational materials [29], Distribute educational materials [31], Facilitation [33], ³⁰ Identify and prepare champions [35].
Audits	Only basic audits for IPC were in place. Other audits pertinent to this site are required.	Develop and implement tools for quality monitoring [26], ³⁰ Develop and organise quality monitoring systems [27], ³⁰ Audit and provide feedback [5], ³⁰ Facilitation [33], ³⁰ Identify and prepare champions [35].
Recipients		
Motivation to change, individual level	No key barriers.	To maintain and enhance: Facilitation [33]. ³⁰
Ability to change, individual level	No key barriers.	To maintain and enhance: Facilitation [33]. ³⁰
Motivation to change, team level	No key barriers.	To maintain and enhance: Identify and prepare champions [35].
Ability to change, team level	Challenges in building a resilient, well-functioning team. Staff deployed were from different institutions, had not worked as a team previously, diverse range of disciplines and specialties. Boundaries experienced include professional, syntactic, semantic, and pragmatic boundaries (pre-operational). Significantly reduced staff to patient ratio compared to pre-COVID-19 (pre-operational). Involvement of multiple external vendors for bed and facility management, cleaning services, security services, and food catering.	Facilitation [33], ³⁰ Identify and prepare champions [35], Recruit, designate, and train for leadership [57], Inform local opinion leaders [38], Build a coalition [6], Conduct local consensus discussions [17], Capture and share local knowledge [7], Create a learning collaborative [20], Create online learning communities [–], ³⁰ Model and simulate change [45], Obtain formal commitments [47], Promote network weaving [52], Provide ongoing consultation [55].

Table 1. *Continued*

i-PARIHS constructs	Main contextual barriers for infection prevention and control ^a	Key ERIC Implementation strategies used ^b [ERIC list number]
Context		
Inner context, local	No key barriers.	To maintain and enhance: Facilitation [33], ³⁰ Identify and prepare champions [35], Capture and share local knowledge [7], Organise clinician implementation team meetings [48], Promote network weaving [52].
Inner context, organisational	No key barriers.	To maintain and enhance: Facilitation [33], ³⁰ Build a coalition [6], Identify and prepare champions [35], Obtain formal commitments [47], Use advisory boards and workgroups [64], Involve executive boards [40], Develop academic partnerships [24].
Outer context	No key barriers.	To maintain and enhance: Facilitation [33], ³⁰ Involve executive boards [40].

^aMain contextual barriers at baseline, unless otherwise stated.

^bDefinitions from Waltz et al²⁰, unless otherwise stated.

Abbreviations: COVID-19: Coronavirus disease 2019; ERIC: Expert Recommendations for Implementing Change; i-PARIHS: integrated Promoting Action on Research Implementation in Health Services; IPC: Infection prevention and control; PPE: Personal protective equipment.

Figure 2. Personal Protective Equipment donning and doffing at CCF@EXPO.

and celebrate wins/milestones with staff and senior stakeholders (extended data files 3 and 6³¹). A 'flat organisational structure' was intentionally adopted to enable open communication and ease of access to facilitators. This non-hierarchical structure was important and necessary for encouraging a constant flow of ground-up innovations and initiatives, especially as few in the team were experts in managing COVID-19 patients.

Importantly, facilitators were given authority, autonomy, support, and resources to implement the CCF@EXPO IPC innovation. Facilitators displayed desirable attributes (16/18, 89%), performed essential tasks (11/13, 85%), and demonstrated a diverse range of required skill sets (14/15, 93%). Facilitators were skilled in addressing task, team,

<p>A. Autonomous robot (TEMI) at CCF@EXPO.</p> <p>Minimising in-person contact time between staff and patients was one of the strategies to reduce the likelihood of transmission of COVID-19 from patients to staff. The autonomous robot contributed to a reduction of 'dwell time' (time spent by healthcare staff in hot zones (patient areas)), from 6 hours 50 minutes to 4 hours 10 minutes per day per healthcare staff within a month of operation. The autonomous robot was used by pharmacists to provide medication counselling to patients and used by patients to contact healthcare staff after-hours.</p>
<p>B. Smart mirror at EXPO CCF.</p> <p>The Smart mirror provided post-staff training support in verification of correct donning/doffing of personal protective equipment (PPE). Regular audits of PPE donning/doffing were also conducted by auditors. Compliance to correct donning/doffing of PPE improved between baseline and 100th day from 97% to 100% for healthcare staff, and from 93% to 98% for non-healthcare staff.</p>
<p>C. Glo-Germ detected on a doorknob indicating inadequate cleaning.</p> <p>Environmental cleaning was performed by a vendor under contract. While cleaning was adequate for the usual use of the EXPO as an exhibition centre, it was suboptimal for IPC purposes. Glo-Germ Tests were used for IPC audits in environmental cleanliness at staff rest areas. Areas that were inadequately cleaned emit a blue glow under ultraviolet light. In particular, high-touch or high-use areas (e.g. table tops, dividers, doorknobs, light switches, toilets, etc.) were audited.</p> <p>Facilitators worked with the environmental cleaning vendor to improve cleaning techniques, clarify requirements for disinfection, and review the frequency of cleaning. The standard operating procedure for environmental cleaning was amended and adopted by the vendor as a result, benefitting other Halls in the CCF@EXPO. Cleaning robots were also introduced to enable 24/7 cleaning services. Regular audits were conducted to reinforce and to monitor cleaning practices. The pass rate for environmental cleaning audits improved from 97% at baseline to 100% by the 100th day.</p>
<p>D. Additional measures for staff protection.</p> <p>Transparent dividers contributed to protecting staff from droplet transmission of COVID-19 during meal breaks, and also served as an additional visual cue to reinforce safe behaviours during these breaks. Alcohol wipes and alcohol-based hand sanitisers were within reach to facilitate hand hygiene and environmental disinfection immediately after meals. Enhanced seating arrangements were in place to allow safe distancing during meal breaks. A monitoring system was in place to track and identify health conditions of staff which required prompt action.</p>

Figure 3. Selected tools and technologies used which improved staff safety.

Table 2. Staff feedback regarding infection prevention and control at early and later timepoints of the implementation. CCF@EXPO: Community care facility repurposed from the Singapore exhibition centre; EXPO: Refers to the Singapore exhibition centre; PPE: Personal protective equipment.

Timepoint	Representative comments
Pre-deployment and/or early in the implementation	<i>Is our PPE adequate to protect us? [I don't want to] bring [the] virus home.</i>
	<i>[I'm concerned about] staff getting tired and risking safety.</i>
	<i>[I'm concerned about] mental fatigue.</i>
	<i>Encouragement [...] will be most helpful too. Many colleagues are trying hard (putting [in their] best efforts out of [their] comfort zone) to handle the ambiguities, fluidities and tasks that they are not familiar with.... (e.g. optometrist in operations role).</i>
	<i>After our EXPO duties, [can] we ... just return to work [referring to base hospital] immediately the next day? ... what if [we] carry the virus and spread to ... co-workers or patients?</i>
End of deployment: When surveyed about the two best things regarding the SingHealth CCF@EXPO experience comments about teamwork, camaraderie, and staff safety were dominant.	<i>Teamwork and responsiveness of the team.</i>
	<i>The people, the culture.</i>
	<i>Feeling of being safe. Camaraderie.</i>
	<i>Camaraderie and food!</i>
	<i>Teamwork and motivation.</i>
	<i>Equality across all disciplines, positive encouragement.</i>
End of deployment: When surveyed about two things that could have been done better, comments about work processes and practices were dominant.	<i>Ensure [d] my safety and well-being is [sic] well taken care [of] in high risk area. ... Infection control staff were on standby to make sure we do our [PPE] donning and doffing without breaching infection control measures.</i>
	<i>More interprofessional practice.</i>
	<i>Contingency planning for various scenarios from the start.</i>
	<i>Too many stakeholders from different organisations. [...] I know it can't really be helped but certain work processes can be optimised without having to go through so many stakeholders. Miscommunication can happen quite easily as messages are passed on from one stakeholder to the next, though not an uncommon phenomenon in teaming.</i>

and individual needs (Table 2), and were able to iteratively move through the four phases of facilitation articulated in the i-PARIHS framework: (a) clarify and engage (identify the problem, get the right people together); (b) assess and measure (appraise the evidence, consider recipients and context); (c) action and implementation (use rapid PDSA cycles); and (d) review and share (audit/re-audit, timely feedback, sustain, spread).¹⁹ Apart from working with staff on the ground, facilitators actively engaged SingHealth organisational stakeholders and decision-makers at the National/Ministry level. Facilitators focused on goals, thus acted as translators and bridges across professional, semantic, syntactic, and pragmatic boundaries.

Discussion

The SingHealth CCF@EXPO required rapid planning and set-up to deliver healthcare to >3000 COVID-19 patients. Clinician facilitators worked closely with experts in IPC to design a tightly woven set of strategies to overcome contextual challenges to ensure staff safety while delivering high quality patient care. To actualize the goal of zero transmission of COVID-19 to staff, the following principles were used as a basis for the planning, set-up, and operations of CCF@EXPO: (a) reduce opportunities for transmission by minimizing staff dwell time in patient areas; (b) reduce risks of transmission by ensuring that physical infrastructure, environmental cleaning, workflows and practices support IPC; (c) enhance staff protection by ensuring staff competency and adherence to correct PPE use; and (d) constant monitoring via audit and feedback mechanisms to quickly identify emerging issues that threaten staff or patient safety. We reflected these principles in the 'characteristics of the innovation' construct within the i-PARIHS framework.

The science of implementation

This deconstruction demonstrates that the SingHealth CCF@EXPO IPC innovation was a piece of implementation research (IR) in action.²⁴ The CCF@EXPO possessed all eight defining characteristics of IR—context specific, addressed challenges relevant to implementation, used fit-for-purpose methods (e.g. rapid PDSA cycles), demand driven, displayed multi-stakeholder and multi-disciplinary engagement at all levels, occurred in the real-world and in real-time, and focused on processes and outcomes.²⁴

The i-PARIHS framework with its real-world applicability to complex multi-dimensional interventions, allowed articulation of what was an organic (and creative) implementation process. However, because the i-PARIHS is usually used prospectively to plan implementation studies, contextual assessments (as per its originators) are posed as questions which facilitators use at pre-implementation to ascertain, select, and tailor implementation strategies.¹⁹ For the retrospective analysis reported in this paper, we adapted the i-PARIHS assessment questions into statements accompanied by a qualitative rubric for allocating scores. While this unusual use of the framework may draw scholarly criticism, we believe that the assessment rubric allows transparent sharing of the methods used in arriving at assessment scores which informed the deconstruction. We offer the rubric as a resource which other clinicians and researchers may wish to adapt for use during this and future pandemics.¹⁴

The retrospective analysis has proven useful in informing our own ongoing efforts in keeping staff safe while treating/caring for COVID-19 patients in CCFs, improving IPC practices, and contributing to a contextually adaptable blueprint for rapid set-up and operations of future CCFs.

The art of implementation

While implementation may seem like a 3-D version of a logic model with inputs–activities–outputs, albeit within a particular context, far more needs to happen for successful implementation. Namely, skillful facilitation, which we showed was able to overcome contextual challenges of the CCF@EXPO IPC innovation. Facilitators used various leadership styles (servant-leader, participative, directive, transformational) as the situation demanded (nature of the problem, purpose, audience, desired outcome).²⁵ Other major skill sets displayed by facilitators include emotional intelligence, project management, as well as change, risk, and conflict management.^{19,26}

Building on the emphasis that the i-PARIHS places on both the role and the process of facilitation,^{18,19} we highlight that the person or ‘being’ of facilitators is equally important, especially in this case where facilitators are also clinician leaders. In her analysis of healthcare leadership in groups and teams, Greenhalgh argues that a leader is “*someone I can look up to, someone I am prepared to follow, whose judgment I trust, and ... who has integrity (and attends to the moral dimension of our work). [...] to be able to articulate a vision on behalf of our team—and to talk about that vision in a way that inspires me. If my leader wants me to commit to something, I want them to show their own commitment first. [...] I want my leader to generate and sustain team spirit, [...] to have excellent personal qualities and to attend skillfully and wisely to the task, the individuals, and the team as a whole.*”²⁷

The CCF@EXPO facilitators embodied these qualities and demonstrated skills in line with leadership processes drawn from organisational sociology.²⁸ They created structures to oversee and coordinate teamwork, afforded psychological safety in creating a culture of collaborative (and no-blame) learning, and promoted team stability (most evidently in their role-modelling of the in-house TLC framework). T (we work as a Team), L (we Learn from one another), and C (we Care for each other). Facilitators engaged staff not just to co-opt their service, but also to address real fears and concerns about personal safety amidst local reports of healthcare workers being infected,⁸ and safeguarding staff mental health (preventing mental fatigue, burn-out, and counterproductive states). Anonymous staff surveys at later stages of the implementation showed increased confidence in leaders, colleagues, work processes and practices. Camaraderie, teamwork, and friendship were dominant memes in late-stage staff surveys.

Towards the end of CCF@EXPO operations, facilitators prepared staff psychologically for returning to base hospitals. Initiatives to smooth the transition included a perpetual online presence to collate photographs and personal stories from staff.²⁹ An online celebratory event officiated by SingHealth leaders provided a symbolic milestone to thank the team and to mark the end of their service at CCF@EXPO. At stand-down, staff had evolved the TLC framework to represent T (Trust in each other), L (Love for one another), and C (having Confidence as a team) (extended data file 3³¹). We propose that successful operation at the CCF@EXPO went beyond application of best practices and frameworks. The principles used by facilitators and IPC experts to achieve zero transmission of COVID-19 to staff, were enacted in a way that engendered mutual trust, love (sense of belonging, empathy, compassion), and care. These values fueled necessary team dynamics for successful implementation of the CCF@EXPO IPC innovation and remain important and relevant.

Learnings for the future

Key learnings from this initiative include: (a) an understanding of contextual challenges during a pandemic, (b) using a wide range of implementation strategies, (c) always putting people first (recipients–staff), and (d) the importance of facilitation in the implementation of complex multi-dimensional interventions. While Singapore was better prepared post the 2003 severe acute respiratory syndrome (SARS) pandemic, the COVID-19 pandemic highlighted the need for additional planning and a comprehensive blueprint for establishing large-scale *ad hoc* medical facilities on short notice. This is to better manage the large number of COVID-19 cases without neglecting those who need acute management of non-COVID-19 illnesses in hospitals.

Limitations and future research

Limitations of this study are inherent to retrospective research, with available data being the main constraint. The use of three assessors is not a limitation but a strength, as prospective implementation studies often use one or two facilitators for contextual assessments. It may be fruitful to investigate transferability of how we implemented the CCF@EXPO IPC innovation to other settings or other types of infectious diseases. Health workforce studies may examine the effect of CCFs on base hospitals in terms of service capacity and diversion of resources for healthcare delivery.

Conclusions

The goal of zero transmission of COVID-19 to staff at a large CCF was achieved via skilful facilitation amidst significant contextual challenges. The use of rapid PDSA cycles anchored by principles to ensure staff safety was instrumental for implementation success. The i-PARIHS framework is relevant and useful for deconstruction of rapid implementation in a pandemic. It can inform preparedness planning for future scenarios of volatility, uncertainty, complexity, and ambiguity.

Data availability

Underlying data

Open Science Framework: The art and science of achieving zero COVID-19 transmissions in staff at a large community care facility in Singapore using implementation science: a retrospective analysis. <https://doi.org/10.17605/OSF.IO/98G5Q³¹>.

This project contains the following underlying data:

- Underlying data_assessment scores.xlsx

Extended data

Open Science Framework: The art and science of achieving zero COVID-19 transmissions in staff at a large community care facility in Singapore using implementation science: a retrospective analysis. <https://doi.org/10.17605/OSF.IO/98G5Q³¹>.

This project contains the following extended data:

- Additional File 1. List of Community Care Facilities in Singapore
- Additional File 2. Assessment rubric adapted from the i-PARIHS framework for this study
- Additional File 3. The 14PS matrix (High-level documentation and rationale for implementation strategies used)
- Additional File 4. Consensus scores for baseline and 100th day
- Additional File 5. Assessment of facilitation (Assessment of facilitation based on i-PARIHS framework)
- Additional File 6. Communication channels to build collaboration, teamwork, and learning
- Standards for Reporting Implementation Studies (StaRI) checklist for this study

Data are available under the terms of the [Creative Commons Attribution 4.0 International license](#) (CC-BY 4.0).

Authors' contributions

EL conceptualized the paper and methods, provided critical input into the use of implementation science, and developed the assessment rubric. WEC piloted the assessment rubric and developed the 14PS Matrix which provides high-level documentation and rationale for strategies used. NT and HKT obtained research ethics approval. LCL and MLL were instrumental in the development and implementation of IPC practices, including audits. Data was collected, collated, and provided by WEC, AT, LCL, HKT, and NT. WEC, AT, SLC, HKT, and NT provided critical review of the assessment rubric; EL refined the rubric. Assessment was conducted by AT, SLC, and NT; results were collated by SLC. EL and WEC had full access to the data in this study; and verified, analyzed, and interpreted the data. Radar diagrams were prepared by SLC. Photos were provided by LCL and WEC. EL prepared the figures, tables, and boxes. EL and WEC drafted and refined the manuscript. All authors reviewed the manuscript, provided critical input, and approved the final manuscript for submission.

Competing interests

No competing interests were disclosed.

Grant information

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Lisa Hall

School of Public Health, University of Queensland, Brisbane, Qld, Australia

This article was a pleasure to read. It was well laid out, and very comprehensive in its use of implementation science to unpack what contributed to the success of the intervention. I would suggest more information be provided in a few areas:

- References to previous literature looking at the use of implementation science in infection prevention and control initiatives. For example the REACH study¹ used a similar approach to quantify implementation - were the findings similar or different? What can we learn about the use of these frameworks and tools in different infection control settings that could help with future work?
- More detail on the intervention components themselves. For example, the training: Who was trained? how? when? was knowledge assessed? Audit feedback: what parts of the infection control program were audited, using what tools? The detail is spread throughout the paper and the appendices but it would be useful to have this pulled together in a table.
- In areas where there were no barriers identified at baseline, perhaps the authors could discuss the contextual enablers that may be present?
- More discussion on the generalisability of the intervention to other settings. What did you learn that would help with the scale up or spread to other sites, particularly outside of Singapore, where the resourcing and attitudes of management may not be as supportive.
- Do you believe this approach would be sustainable outside a pandemic when the incentives for compliance may not be as evident?

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Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Implementation science, infection control, epidemiology, evaluation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 26 Apr 2021

Elaine Lum, Duke-NUS Medical School, 8 College Road, Singapore

Dear Lisa,

Thank you for reviewing our article and providing suggestions for improvement. We will incorporate these as best as we can, in the next version of the article.

Warm regards,
Elaine

Competing Interests: No competing interests were disclosed.

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