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Research paper

Preventing nosocomial infections in resource-limited settings: An interventional approach in healthcare facilities in Burkina Faso

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Abstract *Background:* Nosocomial pathogens are transmitted by contamination of surfaces causing healthcare-associated infections (HAI). The impact of locally produced disinfectant with operational training as a means to improve hygiene in resource-limited healthcare facilities and prevent HAI was evaluated.

Method: In Burkina Faso, 4 types of electro-chlorinator devices that convert salt and water into sodium hypochlorite through electrolysis were installed in 26 healthcare facilities distributed across 3 sanitary districts. The program was evaluated at 4 months and 11 months and performance compared with a control group.

Results: After 11 months, over 90% of the facilities applied 8 of the 11 essential hygiene practices defined by the Ministry of Health, compared to 20% in the control group. 61.5% of the healthcare facilities improved the chlorine concentration of their sodium hypochlorite solutions, reaching an average concentration of 5.1 g/L compared to an average of 2.1 g/L in the control group. Additionally, a cost-benefit analysis demonstrated that locally produced sodium hypochlorite led to daily savings ranging between 2.7 and 53 euros depending on the device compared with the purchase of chlorine tablets.

Conclusion: Results, therefore, suggest that electro-chlorinator devices in addition to hygiene sensitization can be a simple, cost-effective and tailored intervention to reduce the prevalence of HAI in low-resource settings.

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Highlights

- WATA devices can be installed in a wide diversity of low-resource healthcare facilities.
 - Sodium hypochlorite with chlorine concentration above 5 g/L can be produced by trained staff.
 - WATA devices generate daily savings helping healthcare facilities to become independent of the sodium hypochlorite supply.
 - The investment cost necessary to install a WATA device can be offset in a short time.
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Introduction

Healthcare-associated infections (HAI), also known as nosocomial infections, are acquired by patients during the process of care in a hospital or other healthcare facility [1,2]. Such infections are major contributors to morbidity and mortality and point to insufficient hygiene practices within the healthcare facility [3,4]. The propagation of HAI either occurs through parenteral or airborne transmission, in addition to hand contamination [3]. As such, insufficient disinfection of the medical equipment, lack of asepsis during intrusive interventions and hand contamination by the medical staff significantly increase the risk of HAI within healthcare facilities [3].

While extensive data has been gathered on the prevalence of HAI in developed countries, such statistical information is particularly scarce in developing countries [1,3,4]. A systematic literature review conducted by the WHO estimates that the prevalence of HAI among hospitalized patients in developed countries revolves around 7.6% [1]. Research conducted on the prevalence of surgical site infection discloses that the rate of HAI in low and middle countries varies between 1.2 and 23.6%, while the rate in developed countries ranges from 1.2 to 5.2% [1].

HAI can be prevented by improving sanitation and hygiene, including safe medical waste disposal, toilet sanitation, hand washing and access to safe drinking water [5,6]. Sodium hypochlorite (NaOCl) is an important chemical disinfectant that is widely used in health care exhibiting a broad spectrum of antimicrobial activity [7,8]. The biocidal effect of sodium hypochlorite varies depending on the microorganism. For example, 0.1% (1000 ppm) sodium hypochlorite significantly reduces human coronavirus and human parainfluenza virus infectivity on surfaces within 1 min exposure time while a solution of approximately 5000 ppm hypochlorite applied for 1 min produced a 99.9% reduction in hepatitis A virus. WHO recommends sodium hypochlorite at 0.5% or 5 g/L (equivalent to 5000 ppm) for disinfecting surfaces at health care settings and that a minimum residual chlorine concentration of 0.2 ppm is present in drinking water [1,9]. As such, promoting access to sodium hypochlorite in healthcare facilities can contribute to the

improvement of sanitation and hygiene, thereby reducing the prevalence of HAI and generating savings [10].

In Burkina Faso, healthcare facilities are expected to follow the eleven essential hospital hygiene practices which require that they obtain daily access to sufficient levels and high quality of sodium hypochlorite. In practice, lack of means, difficult access to disinfection materials and the lack of sensitization of the medical staff concerning the importance of hygiene practices often leads facilities to underperform [11,12].

A range of electro-chlorinator devices powered by solar energy or by the grid, which transforms salty water into sodium hypochlorite through electrolysis, was developed and adapted to low-income settings. By giving healthcare facilities the tools to produce their sodium hypochlorite, this technology allows for the decentralization of sodium hypochlorite production, fosters the availability of the solution and has the potential to improve hygiene and sanitation within medical structures.

Driven by the conviction of the necessity for policy formulation regarding HAI in developing countries, this paper analyses the impact of providing access to electro-chlorinator devices to healthcare facilities on hygiene compliance and HAI prevalence.

Methods

Sample

Burkina Faso is divided into 63 sanitary districts, which are responsible for the implementation of health programs within their region. Anticipating potential differences between these districts, the sample group is composed of 24 healthcare facilities and 2 hospitals distributed across 3 sanitary districts: Bogodogo, Nongr-Massom, and Boulmiougou.

The facilities were chosen to evaluate the relevance of WATA technology for each type of healthcare facility, regardless of its functionality (Medical Center, Regional Hospital Center or University Hospital Center), its environment (rural or urban), its energy supply (locally produced thermal energy SONABEL or solar networks/

photovoltaic energy) or the volume of its needs, as illustrated in Table 1 (Table 1). The study didn't use a random sampling given that the primary aim of the project was to evaluate the feasibility of introducing electro-chlorinator devices in Burkina Faso as a means to prevent HAI. The diversity of the structures selected was intended to make the sample as nationally representative as possible.

WATA-chlorinated device description

The WATA device produces sodium hypochlorite (equivalent to 6 g/L of active chlorine) using water, salt, and electricity. The saltwater solution (25 g of sodium chloride per liter) is converted into chlorine (sodium hypochlorite) through electrolysis. The active chlorine content of sodium hypochlorite is essential to guarantee adequate disinfection of medical equipment and surfaces. Sterilization must be done with a 0.5% solution, meaning a solution that contains at least 5 g/L of concentrated chlorine [8].

Four WATA devices were used in the study. All of them produce sodium hypochlorite concentrated at 5 g/L:

- WATA- Standard can produce 2 L of disinfectant within 2 h, producing about 8L of disinfectant daily.
- WATA-plus produces 15L of disinfectant in 4 h, producing up to 30L daily.
- Midi-WATA produces 30L of disinfectant in 4 h, and up to 60L daily.

- Maxi- WATA produces 60L in 4 h and 30 min, or up to 120L in daily.

Each WATA is equipped with a programmable timer. This allows the user to program the automatic start and stop of WATA, and therefore of production. Those timers have been specifically selected to meet the local constraints of power outages. In fact, in such a situation, the timer pauses and then resumes where it left off as soon as the power returns.

Study design

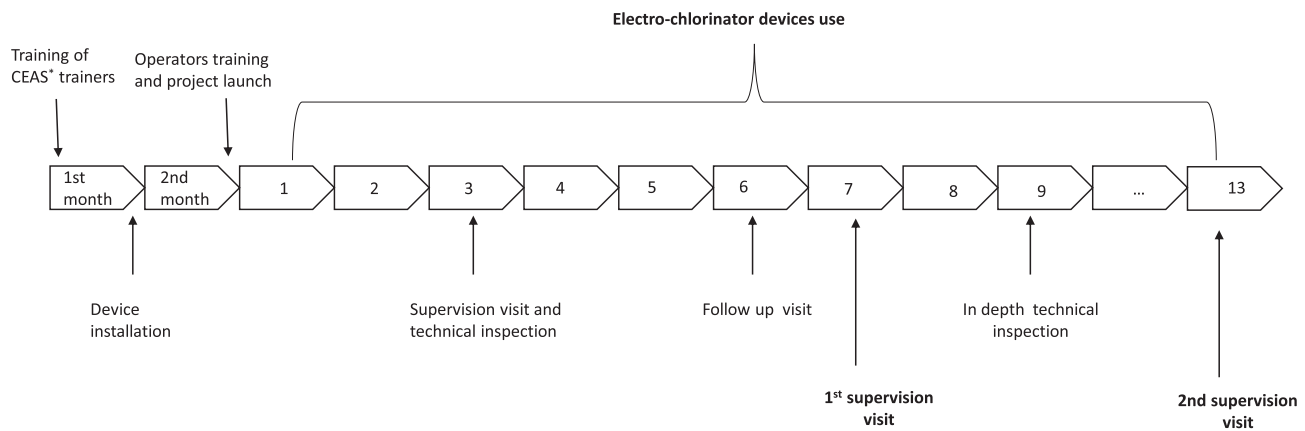
This study aimed to conduct a pilot program to evaluate the relevance of electro-chlorinator devices together with operational training as a means to improve hygiene in healthcare facilities and prevent HAI in Burkina Faso. The pilot was implemented with the collaboration of the Ministry of Health, the Ecological Centre Albert Schweizer (CEAS) of Burkina Faso and the Antenna Foundation.

CEAS Burkina Faso, an association that promotes technological innovation in Africa, trained eleven agents belonging to the health ministry to use WATA devices in addition to sensitizing them to essential hygiene practices, while Antenna Foundation supervised the installation of devices of different sizes in the various healthcare centers selected (Fig. 1). In the distribution of tasks, it was agreed that the Ministry of Health was responsible for raising awareness and promoting hospital hygiene and that

Table 1 Profile of the healthcare facilities belonging to the sample group.

Sanitary District	Healthcare Facility	Environment	Energy Supply	Required volume (L/day)	WATA device
Bogodogo	CM de Bogodogo			60	Maxi WATA
	CM de Saaba			25	WATA Plus
	CSPS de Didri	Rural	Solar	10	WATA Plus
	CSPS de Koubri	Rural		25	WATA Plus
	CSPS Trame d'accueil du secteur 43			20	WATA Plus
	CSPS Trame d'accueil Ouaga2000			10	WATA Plus
	CM urbain de Nagrin			35	Midi- WATA
Boulmiougou	CM de Tanghin Dassouri	Rural		15	WATA Plus
	CSPS du Secteur 14			20	WATA Plus
	CSPS de Komsilga	Rural		15	WATA Plus
	CSPS de Tintilou Sud	Rural	Solar	10	WATA Plus
	CM de Kossodo			60	Maxi WATA
	CSPS du Secteur 13			5	WATA Standard
	CM du Secteur 17			20	WATA Plus
Nongr-Massom	CSPS du secteur 19			15	WATA Plus
	CSPS du Secteur 42			15	WATA Plus
	CSPS du Bang Pooré			5	WATA Standard
	CSPS de Polesgo	Rural	Solar	10	WATA Plus
	CSPS de Roumtenga	Rural	Solar	5	WATA Standard
	CSPS de Sakoula	Rural	Solar	5	WATA Standard
	CSPS de Songdin	Rural	Solar	5	WATA Standard
	Dispensaire de Wendé			5	WATA Standard
	Dispensaire LTNASL			5	WATA Standard
	Dispensaire MACO			5	WATA Standard
CHR	CHR de Koudougou			65	Maxi WATA
CHU	CHU Pédiatrique Charles de Gaulle			40	Midi- WATA

Abbreviations: (CM) medical center, (CSPS) health and social promotion center, (CHR) regional hospital center, (CHU) university hospital.



*Note: CEAS = Ecological Centre Albert Schweizer

Figure 1 Timeline of the pilot project.

Antenna was responsible for ensuring the availability and quality of chlorine through WATA.

Each one of the project partners; the Ministry of Health, the Antenna Technologies foundation and the CEAS-Burkina were present during supervisions. The health units were warned of the visit and it was clearly explained to them that the aim was not to control or judge them, but simply to gather information. The common thread was very similar between the two supervision phases and was materialized by supervision grids which had been established beforehand jointly by all the partners (Appendix 1). Although the control group did not receive any hospital hygiene promotion or electro-chlorinator device, the procedure for supervision was the same.

The program was evaluated at 4 months and 11 months as follows:

1. Hygiene practices. The compliance with the eleven essential hospital hygiene practices defined by the Ministry of Health and the regional health authority, which must be applied systematically to guarantee optimal hygiene in health care facilities, was evaluated by a series of questions and visual inspection on site (Appendix 1). Some health centers were evaluated on less than 11 essential practices because they do not perform childbirth and 3 practices are linked to it. Therefore, it is the % of implementation that was taken into account.
2. Adaptability. To evaluate if WATA device technology is indeed adapted to the wide diversity of facilities the frequency of use, reliability (amount of production) and storage conditions of the sodium hypochlorite generated were evaluated. Questions like: Do you still need to buy/look for chlorine in the market? How often? Were applied in the supervision grid.
3. Quality control of the production. The control of the chlorine concentration of the sodium hypochlorite produced with the electro-chlorinator devices was performed with the WataTest, a reagent that makes it

possible to determine the concentration of active chlorine (Cl₂, HOCl, OCl⁻) of any chlorinated solution, in grams per liter, in a range of 1–7 g/L (0.1–0.7% of active chlorine and 0.32–2.23 °Cl) with an accuracy of ±0.5 g/L. The daily control of the production was performed by the WataTest but for the evaluation carried during supervisions the thiosulphate titration test was chosen to provide better accuracy.

4. Cost-effectiveness. Evaluating the savings that can be incurred by using electro-chlorinator devices to produce a sufficient amount of sodium hypochlorite as opposed to purchasing chlorine tablets. WATA devices are guaranteed for 2 years by the manufacturer but have a much longer lifespan when used correctly (4–5 years easily). The main goal was, therefore, to evaluate if these devices are profitable before the end of their service life so that they can be replaced, if necessary, with the money saved by their use to obtain an economically sustainable system. The analysis took the production costs entailed by the WATA devices into account, namely energy, salt, water and supervision cost. The time dedicated to training was not included as training is also necessary when using chlorine tablets.

A control group of 20 healthcare facilities was introduced to analyze the regular hygiene habits of healthcare facilities and control the chlorine concentration of their disinfection solutions in comparison to the facilities equipped with electro-chlorinator devices. This group was not selected randomly as it was formed based on the structures selected in the sample group in an attempt to compare the results obtained in facilities without electro-chlorinator devices with those undergoing the intervention.

Data collection was done through three different vectors. On the local level, each facility completed a daily update on the performance of its WATA device (volume, concentration, observation). Follow-up visits were additionally conducted by the different sanitary districts' health promotion agents. Finally, two in-depth reports

were compiled by Antenna Foundation, CEAS Burkina Faso and the Health Ministry, collecting the necessary data to validate the results 6 months and a year after the start of the program (Fig. 1).

Results

The analysis of the results is divided into four different themes, each centered around one or numerous key indicators. It is the summary of the 11 essential hospital hygiene practices implementation during the 1st supervision (after approx. 4 months of WATA use) as well as during the last supervision (approx. 11 months after the start of the pilot program). The installation of the devices and training of operators was not performed at the same time in the whole country and the moment of the first inspection one facility was not yet performant. Therefore, the first supervision evaluated 25 out of 26 health care facilities. In the second supervision, 22 out of 26 healthcare facilities were evaluated due to reasons such as the absence of the operator/manager of health facilities (2), theft of equipment batteries (1) or broken equipment (1). During both supervisions, chlorine concentration was not evaluated whenever the electro-chlorinator device was temporarily out of use due to the donation of chlorine tablets by town halls. Therefore, in the first supervision chlorine concentration was evaluated in 22 healthcare facilities and the second supervision in 13 healthcare facilities.

Essential hygiene practices in hospital settings

The contribution of electro-chlorinator devices to the hygiene performance of healthcare facilities was evaluated by comparing the performance of the sample group with the control group.

Data were collected after four months and after eleven months among the sample group. In the former, results showed that 19 out of the 25 healthcare facilities (76%) systematically applied at least 8 out of the 11 hygiene practices.

Data gathered after 11 months suggests an improvement as 20 out of the 22 (90.9%) healthcare facilities systematically applied 8 out of the 11 hygiene practices (Fig. 2). In the control group, only 4 out of the 20 healthcare facilities (20%) systematically applied 8 out of the 11 hygiene practices after 11 months.

Use, dimensions and needs satisfaction

Three indicators are evaluated in this section to access the adaptability of the proposed technology to each health care facility:

The first indicator relates to the use of the WATA device. After 4 months, 17 of the 25 healthcare facilities evaluated were using their WATA device at least every other day, of which 11 reported daily use. The second supervision (11 months) suggested an improvement, with 16 of the 22 facilities supervised using their device at least every other day, of which 12 reported daily use. On average, the healthcare facilities were producing sodium hypochlorite every 1.7 days.

The second indicator analyses the reliability of the electro-chlorinator devices, looking at the average number of healthcare facilities that had been short of sodium hypochlorite over a month due to insufficient production. The average percentage of healthcare facilities facing a shortage reached 8% (2 out of 25) after 4 months and was reduced to 4.5% (1 out of 22) after 11 months. None of the facilities using a WATA device powered by solar panels reported having lacked the power necessary to produce sodium hypochlorite.

Finally, the last indicator looked at the average time during which the sodium hypochlorite produced remained stored before being used. The average storage time defined as appropriate ranged between 0 and 48 h, which corresponds to the use indicator defined above. The supervision effectuated after 4 months revealed that 61.5% (16 out of 26) of the facilities fulfilled the criteria of maximum storage time of 48 h, of which 23% (6 out of 26) stored sodium hypochlorite for 24 h only. The second supervision demonstrated an improvement, with 17 of the 22 healthcare facilities evaluated storing the sodium hypochlorite for a maximum of 48 h (77.2% of the facilities supervised), of which 11 stored its production for a maximum of 24 h.

Chlorine concentration of the sodium hypochlorite solution

The first supervision was effectuated before the study started in 9 centers (exploratory phase). The average chlorine concentration found was 2.2 g/L. Only one out of 9 of the facilities obtained the targeted concentration of 5 g/L (11.1%). After 4 months, a second evaluation was conducted. The average chlorine concentration reached 3.4 g/L, and (5 out of 22) 22.7% of the facilities had a chlorine concentration higher than 5 g/L. The third supervision occurred after 11 months. The average chlorine concentration went up to 5.1 g/L, and (8 out of 13) 61.5% of the facilities had solutions with a concentration above 5 g/L. In parallel, the technical inspection was done applying the thiosulfate titration method. The results obtained revealed that the average chlorine concentration reached 5.42 g/L.

Data was additionally collected within the control group after 4 months to compare the performance of the target group with that of a group with no access to the WATA devices. As illustrated in Table 2, the average chlorine concentration only reached 2.1 g/L, and none of the facilities had a concentration equivalent or superior to 5 g/L (Table 2).

Economic evaluation

A cost-benefit analysis allowed the comparison of the costs incurred by healthcare facilities buying sodium dichloroisocyanurate tablets and those using electro-chlorinator devices.

The resulting numbers suggest that electro-chlorinator devices generate daily savings ranging from 2.7 euros to 53 euros depending on the size of the WATA device and the needs of the facility compared to chlorine tablets.

An additional analysis was conducted to determine the amount of time necessary to offset the costs of purchasing

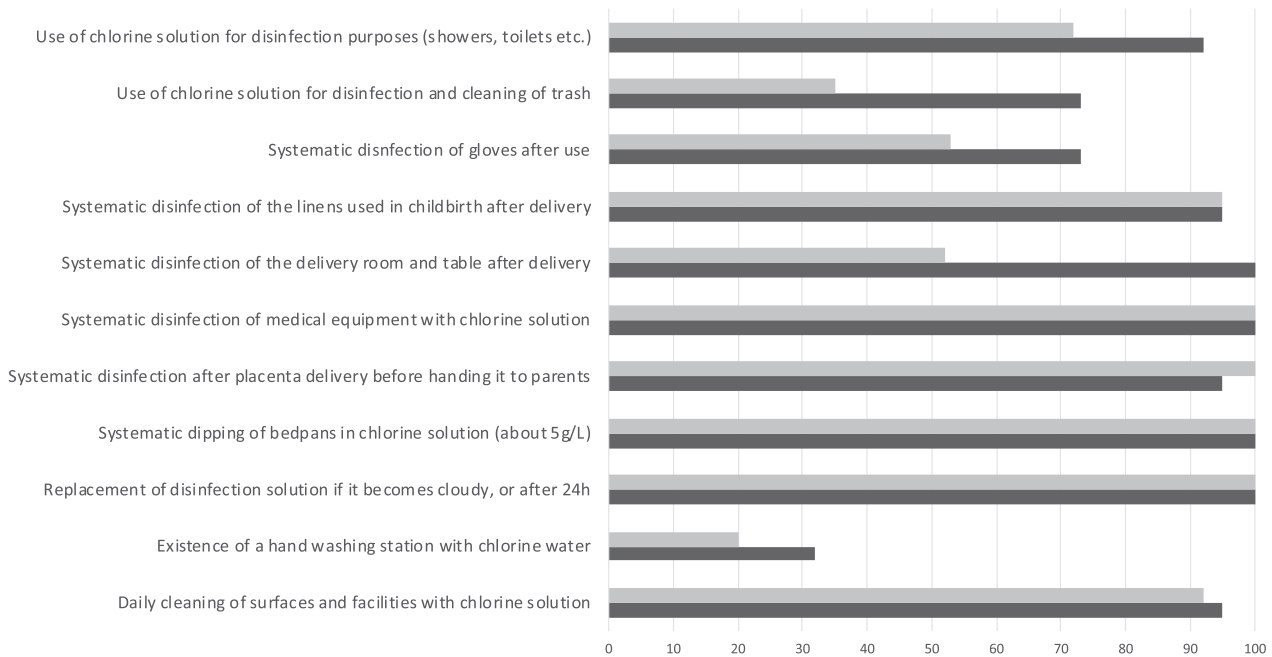


Figure 2 Compliance with the 11 essential hygiene practices after 4 months and 11 months.

Table 2 Active chlorine content evaluation.

	Target Group		Control Group
	4 months	11 months	4 months
Average concentration	3.4 g/L	5.1 g/L	2.1 g/L
Percentage of facilities with a chlorine concentration ≤ 5 g/L	22.70%	61.50%	0%

a WATA device. The results summarized in [Table 3](#) show that the investment cost necessary to equip a healthcare facility with a WATA device is offset after 58–381 days, depending on the healthcare facility's size and the device type ([Table 3](#)).

Finally, it was found WATA installation often leads to an increase in the consumption of chlorine solution for disinfection. Indeed, it is a device that allows independent production and in the desired quantity and this, therefore, pushes many health centers to use this availability for better disinfection. This is not quantifiable financially, but

Table 3 Cost-benefit analysis of electro-chlorinator devices.

	Savings per day (WATA vs tablets)	Break-even point	
		In days	Chlorine (L)
WATA Standard	€ 2,61	161	964
WATA standard (solar)	€ 2,66	381	2 284
WATA Plus	€ 13,02	135	4 051
WATA Plus (solar)	€ 13,31	254	7 263
Midi WATA	€ 25,92	99	5 964
Maxi WATA	€ 52,09	58	6 975

it shows how much chlorine in tablets can act as a limit on needs due to its cost and availability.

Discussion

Essential hygiene practices in hospital settings

Hygiene compliance among healthcare facilities with access to WATA devices and hygiene awareness campaigns significantly improved, while only 20% of the facilities in the control group systematically applied 8 out of the 11 essential hygiene practices. The significant differences observed between the two groups may in part have stemmed from the difficulties encountered by the average healthcare facility to have reliable access to a sufficient amount of quality disinfecting solution for their hygiene needs. As such, the higher rate of compliance with the hygiene norms listed by the Ministry of Health among facilities with access to electro-chlorinator devices suggests that improved access to sodium hypochlorite may foster hygiene compliance.

Insufficient knowledge regarding the importance of fulfilling all of the 11 hygiene practices may additionally have contributed to a worse score among the facilities of the control group, hinting to the necessity of hygiene

sensitization. This suggests that while electro-chlorinator devices correlate with an improvement in hygiene practices among healthcare facilities, the program may be more impactful when combined with hygiene sensitization. These results are consistent with literature about nosocomial infections and hygiene compliance, which indicates that hygiene training is essential to achieve a behavior change among healthcare workers and foster compliance with hygiene protocols [13–16].

Use, dimensions and needs satisfaction

The initial data gathered after 4 months revealed that 8 out of 25 (in the sample group) were using their device at a lesser frequency than every other day. This result however improved after 11 months, where 73% (16 out of 22) of the facilities reported using their device at least every other day. This result may have been impacted by the fact that most hygiene facilities were initially not applying all 11 of the hygiene practices defined by the Health Ministry. As a result, these facilities may have been under-using their electro-chlorinator devices. This hypothesis is supported by the data collected after 11 months, in which a higher percentage of facilities report using their device every other day. The awareness campaigns relating to the importance of hygiene in healthcare facilities and the availability of chlorine solution may have improved the compliance of the medical staff with hygiene practices [14]. The average percentage of health units that experienced a problem with WATA during a month was 4.3% compared to 7.7% during the first supervision which is low.

Chlorine concentration of the sodium hypochlorite solution

The chlorine concentration found up until four months after launching the project revealed that the quality of the disinfection solution produced with the electro-chlorinator devices was only sufficient among (5 out of 22) 22.7% of the healthcare facilities in the sample group. The data collected after 11 months, however, suggested improvement as (8 out of 13) 61.5% of the facilities were producing a disinfection solution of adequate concentration. The rising percentage of facilities abiding by the concentration standards suggests that some time may be necessary to allow the users of electro-chlorinator devices to familiarize themselves with the WATA technology and reach an adequate chlorine concentration of at least 5 g/L.

The data gathered after 11 months allows for a comparison between the sample and the control group. 61.5% of the facilities with access to electro-chlorinator devices were found to have a solution with a chlorine concentration equivalent to or higher than 5 g/L. However, this threshold of chlorine concentration wasn't reached by any of the facilities belonging to the control group, which were using other chlorine types found on the market such as chlorine tablets or bleach. These results, therefore, highlight the imperative need for a chlorination method such as electro-chlorinator devices to allow healthcare facilities to produce a disinfectant of sufficient quality and an adequate chlorine concentration.

Economic evaluation

The investment cost necessary to equip a healthcare facility with a WATA device is offset in a maximum of 381 days which is less than the 2 years guaranteed by the manufacturer or the usual lifespan of the product when used correctly (4–5 years). The solar kits were also performant during the rainy season and this was very reassuring for the implementation of the electro-chlorinator devices in rural areas. Although not financially quantifiable, a device that allows independent production and in the desired quantity is even more important for isolated areas.

Limitations

Some limitations may impact the accuracy of the results found. Improvements in hygiene were measured by referring to the eleven hygiene practices defined by the Ministry of Health of Burkina Faso. This approach could have been complemented with an epidemiological study comparing the prevalence of HAI in healthcare facilities with and without access to WATA devices. The combination of these two methods of evaluation would allow for a more accurate evaluation of the contribution of electro-chlorinator devices to the improvement of hygiene practices and prevention of HAI.

Also, there may be some baseline differences between the control and the sample group given that their selection was not random. This may additionally limit the reliability of the associations observed between the intervention and the outcomes.

These limitations can be taken into account when conducting future studies related to the prevention of nosocomial infections in medical settings.

Conclusion

The pilot study conducted in Burkina Faso provides an insight into the potential for electro-chlorinator devices to significantly improve hygiene compliance in healthcare facilities in low resource settings, and thereby contribute to the prevention of nosocomial infections. The provision of electro-chlorinator devices in healthcare facilities allowed these structures to have access to sufficient amounts of sodium hypochlorite, which promoted compliance with the eleven essential hygiene practices defined by the Ministry of Health. Besides, a cost-benefit analysis confirmed that the initial investment cost for a WATA device could be offset within the first year and that sodium hypochlorite production through an electro-chlorinator device generated significant savings in comparison to the daily purchase of chlorine tablets. Therefore, electro-chlorinator devices in addition to sensitization to essential hygiene practice could be a simple, cost-effective and tailored alternative to reduce the prevalence of health acquired infections in low-resource settings.

Ethics

The program was approved by Burkina Faso Ministry of Health.

Authorship statement

P.G. Duvernay, conception and design of the analysis;
 E. de Laguiche, manuscript writing;
 R. Campos Nogueira, manuscript writing and reviewing;
 B. Graz, manuscript reviewing;
 L. Nana, data collection;
 W. Ouédraogo, manuscript reviewing;
 Y. Sauter, data collection and analysis;
 E. Sauvageat, data collection, and analysis.

Declaration of Competing Interest

Antenna Foundation developed WATA™ technology.

Funding

Antenna Foundation financed the water chlorinated devices and project concept; CEAS and Ministry of Health financed human resources for implementation.

Provenance and peer review

Not commissioned; externally peer reviewed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.idh.2020.04.003>.

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