Standardized Test Method to Assess the Functions and Working Characteristics of Handrub Dispensers

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Abstract: Hand hygiene with Alcohol-based handrub (ABHR) is commonly employed in healthcare facilities, and dispensers are the primary means of delivering handrub during hospital work. The reliable dosing of these dispensers is a crucial, yet understudied issue. The volume of the handrub had a large impact on the quality of hand hygiene. In our experience involving human subjects, it was hard for the subjects to quantify the dispensed volume: people could not perceive if the dispenser provided inadequate volume. This article aims to establish a standardized method, summarize the parameters and approaches through which dispenser reliability shall be assessed. The new protocol was tested on a range of existing ABHR dispenser to demonstrate its versatility. 13 different marketed dispensers were investigated in this study, and both liquid and gel format handrubs were tested whenever feasible. The test protocol addresses the measurement of various parameters, including dispensed volume, accuracy, consistency, time dependency, energy consumption, sensor activity, the impact of handrub level and dosing during run-out phase. In the case of most tested dispensers, the actual dosed volume was below 1.5 ml, below the recommended minimum. Dispensed volume could be legitimately different when different handrub formats (liquid or gel) are used. Some dispensers did not provide consistent doses when they were not in operation for an extended period of time. Remarkably, after just 5 minutes of non-use, some dispensers reduced the dispensed volume by half. The time-dependent decrease varied among product formats. Detection activity showed considerable variations, one dispenser checked for hands seven times more than another. With decreased handrub level, the volume may increase or decrease, depending on the construction. The assessment protocol was established and proven in practice. There was no perfect dispenser found, critical issues have been identified with the help of the structured measurements. Given the diverse needs of hospital wards, a standardized, comparable description and assessment of dispenser characteristics could assist wards in selecting the most suitable dispenser. This study encourages manufacturers to conduct these product tests and share their results along the open science principles.

Keywords: hand hygiene; handrub dispensers; ABHR dispenser; hand hygiene monitoring; digital infection control; hospital infrastructure; digital medical devices; healthcare quality assurance

1 Introduction

Hand hygiene is the basis of infection control in hospitals. Alcohol-based handrubs (ABHRs) are on the World Health Organization's (WHO) essential medical list, no hospital work is feasible without using it [1]. ABHRs are provided by dispensers, so the reliable working of these dispensers is an important issue that has received surprisingly little attention within the scientific community until recently.

A prior study described reliability issues in the case of common handrub dispensers [2]. That study primarily focused on manual and regular dispensers, highlighting their time-dependent reduction in dispensed volume, leading to insufficient dosing of ABHR, therefore creating a major patient safety black spot. Gravitational dispensers did not exhibit this time-dependent fault, yet, they could demonstrate other deficiencies. Another outstanding publication described a set of local requirements for hospital dispensers [3].

Recently published ISO standard on hand hygiene in healthcare (ISO 23447:2023) set recommendations with respect to infrastructure management [4]. It also mentioned the ABHR dispensers and the claim that only closed system dispensers would be acceptable in hospitals.

The reliable functioning of dispensers is crucial, especially concerning hand hygiene monitoring systems, which rely on consumption of ABHR. The prevalent monitoring systems in hospitals directly link hand hygiene to dispenser usage. It has long been proved that without sufficient ABHR, it is impossible to achieve complete coverage and disinfection of the hands. Testing the reliability of the clinically employed dispensers becomes inevitable to ensure accurate data recording and quality assessment. The monitoring systems have become more widespread, most western hospitals will likely adopt them in the near future, in order to adhere to mounting institutional reporting responsibilities. To date, there is not any published set of criteria along which these systems could be fully validated, and some system's reliability often raises serious questions.

This article aims to summarize the parameters that should be tested and validated to objectively describe the functions and operation of an ABHR dispenser. The study seeks to provide scientific evidence on the essential performance of dispensers, establish reliable test protocols and evaluate these protocols to demonstrate their effectiveness in identifying malfunctions accurately.

2 Materials and Methods

This study presents a test protocol to describe the working characteristic of dispensers. Infection prevention related guidelines and protocols gained much attention during and after the pandemic period [15]. It is important the extend the range of evidence to be provided, especially along new digital medical devices, as the mounting regulatory requirements demand extensive liability from the manufacturers, especially since the introduction of the Medical Device Regulation in Europe [16]. First, a complete, evidence-based test methodology was developed for ABHR dispensers, and second, various dispensers were collected and tested according to that protocol to validate it.

2.1 Dispensers Involved

In the context of the research everything was considered as a dispenser that can provide and dose ABHR. Table 1 provides a list of all the dispensers involved in this study. Three main dispenser types were identified: plastic bottles and two variations of wall-mounted dispensers: manual and touchless (automatic). We adhered to the nomenclature described in the study Bansaghi et al. 2020 [2]. An *open system* contains a fixed ABHR reservoir that is refilled, or topped up from a bulk product. This typically refers to refillable dispensers and dispensers with a fixed pump, where only the ABHR bottle is replaced. On the contrary, a *closed system*, is when all parts that come into contact with the ABHR during each refill. According to the new ISO regulation, open, user-refillable systems should not be used in hospitals. Despite this, some institutions prefer open systems because they can be refilled with any handrub product, making it easier for the hospital to switch between ABHR suppliers [4]

Table 1
Dispensers involved in the study

Dispenser type	Manufacturer	Dispenser's description	ABHR name (Format)
BBM Touchless	BBraun	Wall-mounted, Gravitational, Automatic, Closed system	Softa-Man Pure (Liquid)
			Softa-Man Viscorub (Gel)
LTX	GOJO		Purell Advanced (Gel)
Medline	Spectrum		Spectrum Medline (Gel)
Nexa	Ecolab		Ecolab Express Gel (Gel)
Purell ES-8	GOJO		Purell Advanced (Gel)
Simex	Ecoclean	Wall-mounted, Gravitational, Automatic, Open system	Sterillium (Liquid)
			Spirigel (Gel)

Dermados	Ecolab	Wall-mounted, Regular, Manual, Open system	Sterillium (Liquid)
			Spirigel (Gel)
Ingo-Man 26	Ophardt		Sterillium (Liquid)
			Spirigel (Gel)
Alcohol Gel	Tork	Plastic bottle (Regular, Manual, Closed system)	511103-08 (Gel)
BradoGel	Brado		BradoGel (Gel)
Sanytol	AC Marca		Sanytol Gel
Softa-Man Viscorub	BBraun		Softa-Man Viscorub (Gel)
Spirigel	Ecolab		Spirigel (Gel)

We intended to select the dispensers most frequently used in healthcare and public settings. We attempted to obtain information on the actual dispensers hospitals use, ideally by country, but we were unable to find this data or national reports. Therefore, the selection of dispensers was based on the researchers' impressions based on domain knowledge and secondary market research.

Dispensers were tested with their own refills, whenever available. For refillable dispensers, we uniformly used Sterillium as a liquid and Spirigel as a gel format ABHR, as these products are widely used in hospitals.

In this manuscript, dispensers were anonymized and signed as Dispenser #A through #M, in an order differing from their list in Table 1 to preserve objectivity.

2.2 Test Protocol

Tests were carried out under normal laboratory conditions (room temperature between 22 and 24 ºC, with no extreme ambient parameters), similar to typical clinical usage. Wall-mounted dispensers were fixed on the wall.

The investigation for each system started with a newly opened dispenser or refill. In the case of battery-operated dispensers, table-top bench power supply (Voltcraft LPS1153) was used to eliminate the bias caused by not completely charged batteries. The voltage was set to match the nominal voltage of the batteries (e.g., if the dispenser operated with four 1.5 V batteries, then 6 V was applied).

For each dispenser type, it was specified whether the dispenser can only be used with a fixed volume or provides the option to adjust the target volume. If the volume was adjustable, it was set to the minimal volume, unless otherwise stated in the specific parameter description of that measurement.

To initialize the dispenser, 10-20 dispenses (dosing events) were carried out, depending on the total hand rub capacity of the dispenser. Figure 1 shows the applied test protocol.

The mass of each dispensed dose was recorded by a laboratory scale (Ohaus Navigator NV622). Mass was converted to volume using the official density of the applied handrub, found on the product's Safety Data Sheet, usually in Section 9 (Physical and Chemical Properties), expressed in g/cm^3. The same researcher performed all the measurements.

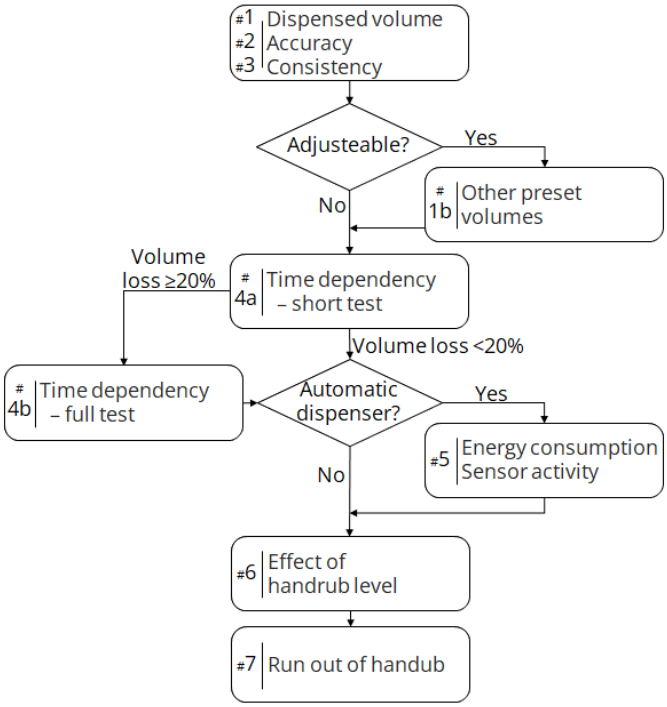

Figure 1
Generalized test protocol for ABHR dispensers: sequence of the tests of different parameters

2.2.1 Dispensed Volume

The *dispensed volume* is the actual measured volume of ABHR that a dispenser provides (baseline volume). To describe the average dispensed volume, 50 consecutive doses were recorded. The average value of the 50 recorded doses was computed. If the dispenser was adjustable, additional nominal volumes were also measured the same way.

2.2.2 Accuracy

Accuracy can be calculated as the dispensed volume divided by the pre-set (or nominal) volume. The nominal volume represents the expected quantity that a dispenser should deliver based on the system's user guide or specifications when

operated once. In the case of an automatic dispenser, this meant activating the sensor once. Usually, some documentation describes what volume the dispenser should provide. A perfect, 100% accuracy value means that the dispenser provides exactly the expected amount.

2.2.3 Consistency

Consistency describes how uniformly the dispenser can provide the doses. The more uniform the doses are, the more reliable is the dispenser system. The same data of the 50 doses (described in the '2.2.1 Dispensed volume' section) were used to calculate minimum, maximum, Q1 and Q3 data, in addition to the average.

The 50 doses were determined for practical reasons: in most cases, collecting more than 50 doses would deplete the ABHR supply, leaving insufficient ABHR for subsequent tests. A higher sample size would be needed to detect deviations with certainty. With 50 doses, there is a possibility that some discrepancies may go unnoticed.

2.2.4 Time-Dependency

Volume loss is the difference between the baseline volume and the dispensed volume following a specified duration of non-use, during which the dispenser is left idle. Previous study provided a detailed description of the time-dependency [2], and concluded that volume loss over time proved to be a common problem. The cause of this problem lies in the pump mechanism design, the gradual trickling down of the handrub inside the pump.

Volume loss is always increasing over time, never decreasing. That is why we started with a shortened time-dependency test. It is just measuring the first two dispensed doses after 16 hours of non-use. If the decrease was less than 20% of the baseline volume then no further investigation was required, and the performance of the dispenser was deemed acceptable in general.

16 hours of non-use was selected for a practical reason: this is the time interval while the dispensers typically remain unused in a clinical setting after an 8-hour regular workday. Consequently, the 16-hour sample can be conveniently collected on the following morning.

For the detailed test, the first two dispensed doses were measured after 5 min, 15 min, 1 hour, 4 hours and 16 hours of non-use.

2.2.5 Energy Consumption

Energy consumption test is applicable only to the battery-operated dispensers. The usability of the dispenser is low if the battery depletes too soon. In this case,

most of the dispensers would not work, as in hospitals the dispensers cannot be checked often enough.

At first, energy consumption during non-working was measured. Automatic dispensers have to continuously look for a hand, and usually, they also have an LED-light. Typically, they follow a cycle of waking up, checking for a hand and returning to stand-by if none detected. This pattern results in minor, but regular peaks in energy consumption.

Sensor activity measurement assesses how frequently the dispenser "wakes up" to check for hands, providing insights into its responsiveness. A higher sensor activity indicates a faster response to hands beneath the dispenser.

Energy consumption during dispensing (operating the pump) was also investigated.

2.2.6 Effect of Handrub Level

The decrease of the handrub's volume within the dispenser's container during the use can largely impact the dispensed volume. To explore the effect of the handrub's level, we conducted measurements using a refill containing 25% of the original volume, and compared these data with their baseline volume.

2.2.7 Run out of Handrub

As the handrub level in the tank decreases, the dispenser initially begins dispensing incomplete doses before completely stopping. If this under-performance is not monitored properly, it may lead to insufficient dosing, and this transition phase can be considerably prolonged, depending on the design and the control software of the dispenser.

All dispensed doses were individually measured starting from a predefined point: when the dispenser had 5% of the original volume and also at the volume equivalent to 40 baseline volume (measured during the first test) still present in the tank or refill. The measurement concluded when the dispenser consistently provided 0.00±0.01 g of handrub for three consecutive cases.

3 Results

We will not present all the numeric results measured with the 13 dispensers and across all test parameters. Instead, our focus will be on highlighting cases where we observed non-uniformity in dosing. The primary objective of our study was to demonstrate that each tested parameter can influence dosing, and hence it is worth to test.

3.1 Dispensed Volume

Figure 2 shows the average dispensed volumes (baseline volumes) for the examined dispensers. If the dispenser was adjustable (different volumes could be selected) all the possible settings were tested. This figure shows only the data measured when gel-format handrubs were used, as this was the format tested across all dispensers. As depicted in the Figure, the typical dispensed volumes ranged between 0.8 and 1.5 ml. Only one of the investigated dispensers could be set to the volume over 2 ml. This means that most clinically applied dispensers should be operated twice to provide the necessary recommended volume for a complete hand hygiene, which shall be indicated in their user manual and made part of the user training.

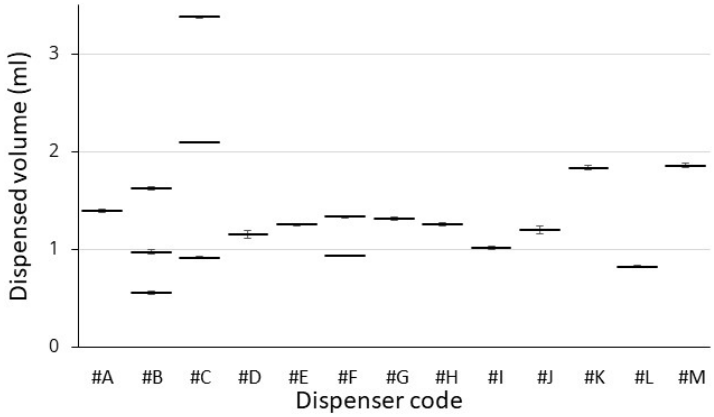

Figure 2

Dispensed volumes (baseline volumes) when dispensers were used with gel-format ABHR. Data shows the average dispensed dose ± the standard deviation. In the cases when the dispensers were adjustable, all the possible volumes were tested.

Four dispensers were also tested with liquid format ABHR. In one case, the same dispenser provided different amounts when different format ABHRs were used (Figure 3, Dispenser #D), while in other cases, the volume was format-independent (one example is shown in Figure 3, Dispenser #C). Note, that this difference was never mentioned when the nominal dose was documented in the product description.

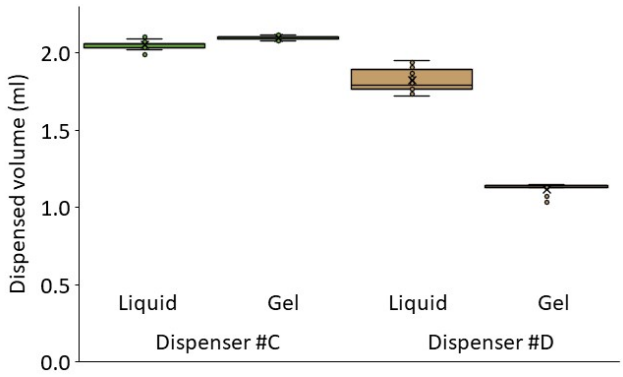

Figure 3
Volume of doses provided by the same dispenser, when different formats (liquid or gel) handrub were used. Format choice may affect the provided volume.

3.2 Accuracy

Accuracy tells us what volume provides the dispenser compared to the volume that it should provide (the nominal volume). Figure 4 shows the dispensed volumes in the case of two different dispensers. In both cases, their product descriptions claim that the dispenser provides exact 1.5 ml handrub. While these dispensers were expected to provide the same amount of ABHR, during the tests Dispenser #C provided 48% more ABHR than Dispenser #A.

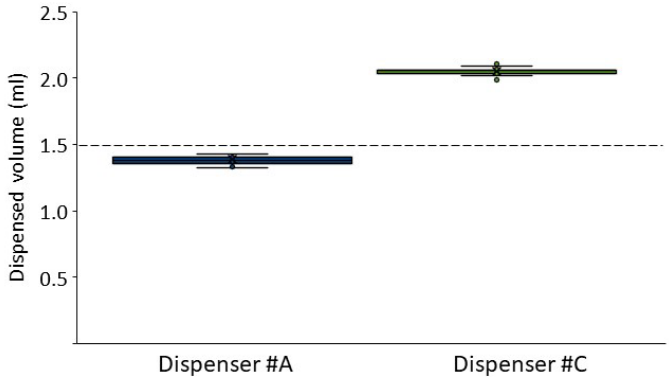

Figure 4
Dispensed volumes in the case of two dispensers. The nominal volume (that the dispenser should provide) was 1.5 ml in both cases (1.5 ml marked with a dotted line).

A clear and standardized definition is necessary to clarify the meaning of a *dispenser providing 1.5 ml*. Some manufacturers interpret this as the average

dispensed dose of 1.5 ml. Conversely, for other manufacturers, it implies that the vast majority of doses should exceed 1.5 ml, to avoid any patient safety related issues.

3.3 Consistency

Consistency describes the variability of doses. Figure 5 compares two dispensers: one was set to 1.0 ml, while the other to 0.6 ml. The actual, average doses were close to these values: 0.99 ml and 0.76 ml, respectively. However, it is noteworthy that the dispenser with the higher volume setting delivered one time the lowest dose (0.51 ml) due to notable variability in dosing under those specific conditions.

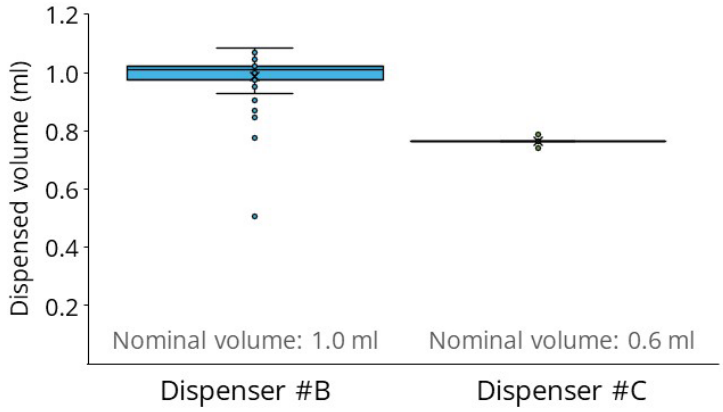

Figure 5
Dispensing consistency of two different dispensers. Dispenser #B was set to 1.0, and Dispenser #C to 0.6 ml. The figure presents 50 doses in each case.

3.4 Time-Dependency

Time dependency shows how the dispensed volume differs from the baseline volume after a non-use period. Figure 6 shows an example of the time-dependent volume loss. Dispenser #B provided only half of the baseline volume even after 5 minutes of rest, and one-third after 1 hour. Following the rest period, both the first and second doses were individually measured. A prior study indicated that depending on the pump structure, volume loss can occur either at the first dose or at the second one [2].

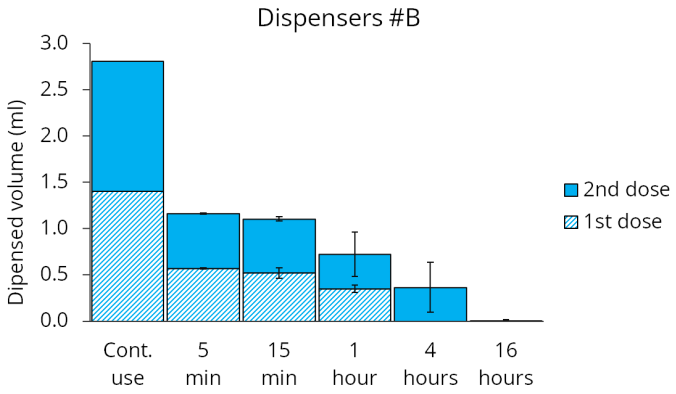

Figure 6

Time-dependency in dosing: Following a period of non-use, this dispenser doses less volume compared to its continuous operation. The volume loss increases as the time elapses.

The same dispenser had different time-dependent characteristics when different ABHR formats were used (Figure 7). Volume loss is more typical with liquid handrub, probably due to the higher viscosity of gel, preventing trickling and dripping [2]. Some manufacturers retrofitted pump mechanisms originally developed for liquid soap dosing, which are much closed to gel format ABHR in viscosity.

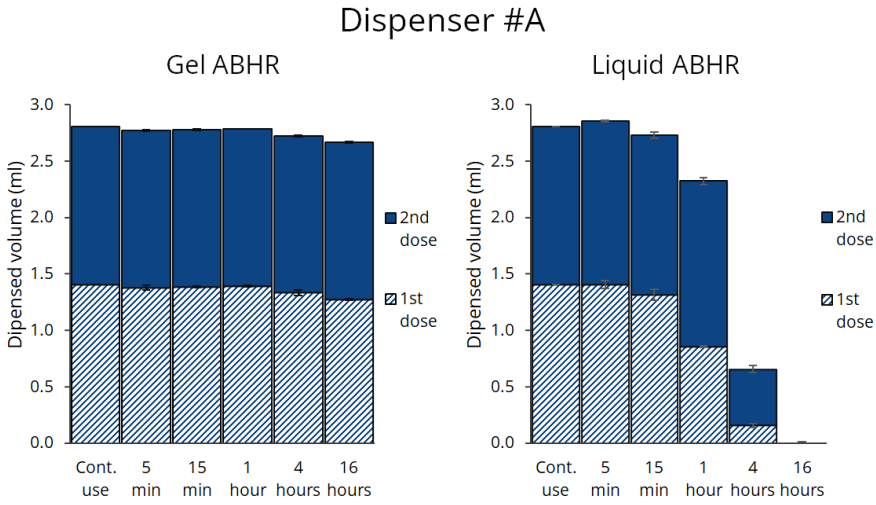

Figure 7

Volume loss after different non-use periods, when the same dispenser (Dispenser #A) was filled with gel (left) and liquid handrub (right). It is typical that volume loss is more significant when liquid handrub is used.

Volume loss always increases as time elapses. To shorten the experimental protocol, the 16-hour time point was measured first, as depicted in Figure 8. If the volume loss was less than 20%, no further measurements were necessary. In our case, we measured more than 20% volume loss only in 5 out of 16 measurement cases, linked particularly to 3 dispensers. In the case when more than 20% volume loss was detected, we recommend measuring all time points to comprehensively evaluate the significance of the parameter (i.e., whether the volume loss is significant within 5 minutes or only after hours).

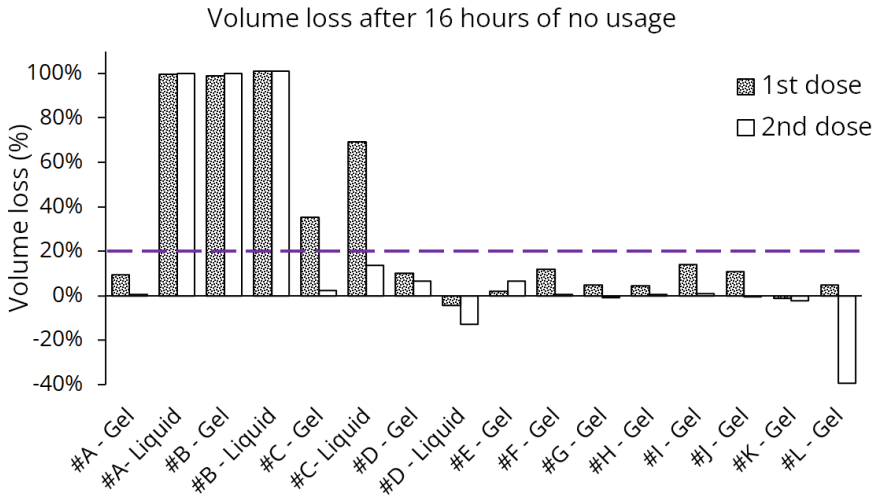

Figure 8

Volume loss following a 16-hour resting period. 20% volume loss was chosen as the threshold value: if a dispenser lost more than 20% volume after 16 hours, additional time points were also measured. (Note: The change observed at the Dispenser #L can be explained by the effect of the handrub level, as explained later.)

3.5 Energy Consumption

Energy consumption was calculated during the standby-state, and also during dosing operation. Naturally, these types of investigation are only indicated for automatic, touch-free dispensers.

3.5.1 Standby Energy Consumption, Sensor Activity

Automatic dispensers have to continuously scan for the presence of hands. Figure 9 shows the standby energy consumption of three dispensers (#B, #C, and #E). Small, regular peaks are observed, signing that the dispensers are periodically waking up, checking for a hand, and returning to stand-by if none is detected. The average energy consumption was 1.63, 1.85 and 0.72 mW, respectively.

Dispenser #E used half energy compared to Dispenser #B. That means Dispenser #E needs less frequent battery changes. Consequently, it entails less maintenance.

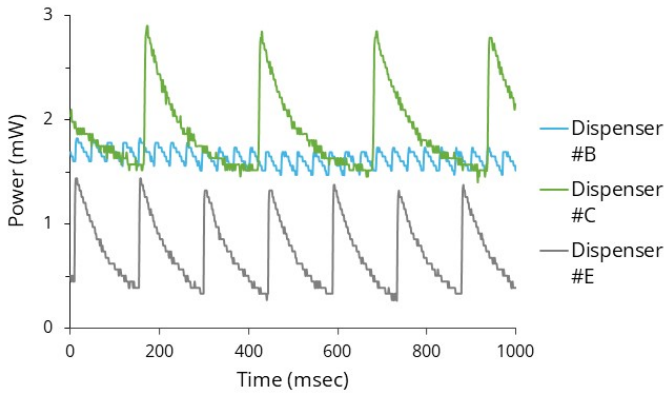

Figure 9
Energy consumption of three touch-free dispensers in the time window of 1 second, while they were in standby mode

Note in Figure 9 that not only the average energy consumption differs, but also the frequency of the working and stand-by cycles. Dispenser #E checks for hand twice as frequently as Dispenser #C. This can be described by the sensor activity: the number of cycles in one second, which was 28, 4 and 7 for Dispensers #B, #C and #E, respectively. Sensor activity indicates how often the dispenser checks for hands; a higher frequency allows for quicker reactions to hands showing up underneath. Slow reaction can be a relevant usability problem: people place their hands under a dispenser, and if receiving nothing, they remove them (and hopefully try again). In case the dispenser was merely slow, then it would dispense late, when the hands were already removed, hence not only producing waste but also wetting floor around the dispenser and mounting frustration in the user.

3.5.2 Energy Consumption during Dosing

Figure 10 illustrates that the energy consumption during dosing is three orders of magnitude higher than during standby mode. The Figure compares the energy consumption of three dispensers (#C, #E and #H) during a single dosing period. The average energy consumption was 0.64, 0.99 and 1.40 W, respectively. These differences can impact the frequency of needed maintenance based on the battery's lifespan, as described above. The sharp spike in energy consumption at the beginning of the cycle can also lead to a difference in battery lifetime.

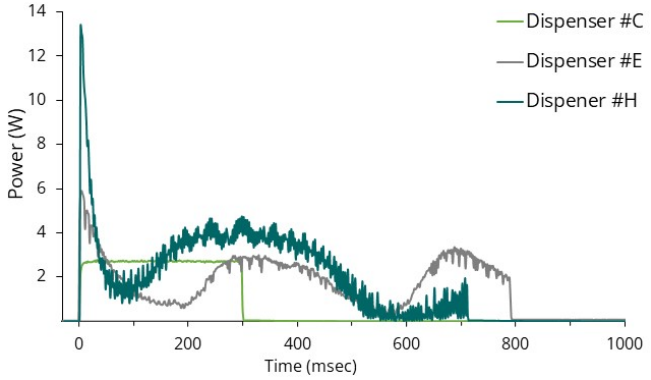

Figure 10

Energy consumption during dispensing. Note that the energy consumption is not uniform during the dispensing. In some cases, there is a big spike at the beginning.

3.6 Effect of Handrub Level

As a dispenser begins to deplete, the dispensed dose may change. Figure 11 shows three different dispensers. In the case of Dispenser #D, the AHBR level did not affect the dispensed volume. Dispenser #H delivered a slightly decreased dose as the handrub level decreased. Conversely, Dispenser #L demonstrated the opposite trend, the dispensed dose increased during usage. This underscores the fact that all three scenarios are possible, depending on the design of the dispenser.

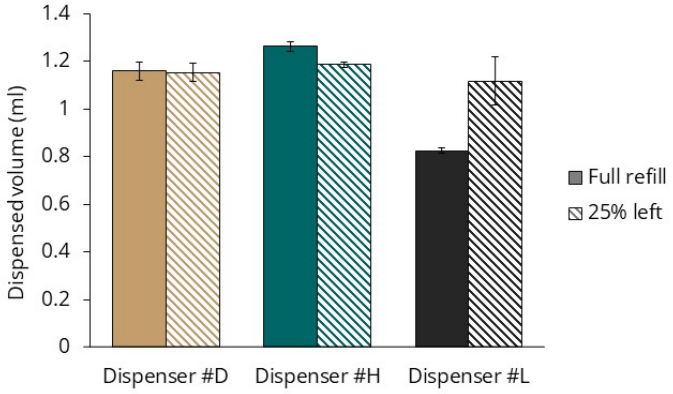

Figure 11

Impact of handrub level on dosing. Dispensed volumes were measured when the refill/bottle was almost full (n=50), and when only 25% of the original handrub amount was left (n=10). As the handrub level diminished, the dispensed dose could decrease (Dispenser #H), increase (Dispenser #L), or remain unchanged (Dispenser #D).

3.7 Run-out of Handrub

Figure 12 shows all doses provided by a plastic-bottle dispenser. When a new bottle or refill is opened, some stokes/dispenses are necessary to get the dispenser working properly ("pumping up" the system). It is a well-known phenomenon, yet, should be properly addressed in the user guide. As the Figure shows, the volume of the first three doses is smaller than the subsequent ones. We refer to this initial phase as *initialization*. Following that, during the *normal operation* phase, the dispenser consistently provides the standard volume. Eventually, the dispenser starts to run out of handrub ("run-out" phase). An ideal dispenser would provide the last "normal" dose (close to the nominal volume), and then stop working and signaling a need for refill. In reality, this is never the case. There are considerable variations among dispensers concerning the duration of the run-out phase, depending on their design. The scenario in Figure 12 is quite extreme; after 98 normal doses, the dispenser provided 120 decreased doses during the run-out phase. As previously mentioned, it is really challenging for the clinicians to estimate the real volume of the dosed handrub, therefore people may not even notice when they receive a reduced amount. As long as people get some handrub, they may not notice that the dispenser needs to be refilled.

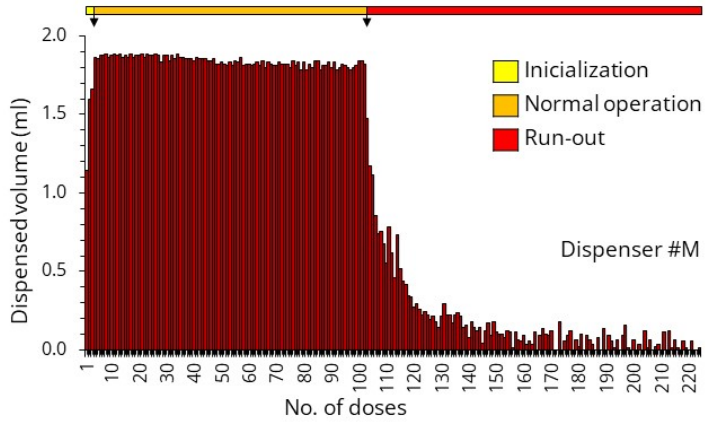

Figure 12

Volumes of all doses Dispenser #M provided. The initial three doses had reduced volume, belonging to the initialization phase. Then, the dispenser provided consequent doses, during the normal operation phase. As the refill bottle began to run out, the dispensed volume gradually decreased until it eventually ceased (run-out phase), providing nothing for three consecutive trials.

In this specific case (Dispenser #M), a total of 4.4 ml of handrub was dispensed during the initialization phase, 180.31 ml during the normal operation, and 23.43 ml during the run-out phase. Even after the dispenser ceased dosing, there was still 25.93 ml of handrub left in the bottle, as shown in Figure 13. Despite applying more run-out doses than normal doses, the majority of the handrub

(77%) was dispensed as normal doses. The initialization volume is negligible, and the remaining amount is considered as loss. A difficult quality-assurance related question is how to judge what to do with the run-out quantity. Discarding the bottle before the run-out phase ensures reliable dosing but results in wasting 10% of the disinfectant, which is a significant amount. Fortunately, as mentioned earlier, this is an extreme case, and run-out volumes are typically smaller.

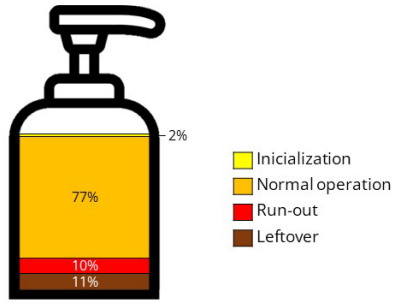

Figure 13

Volumes of handrub that were dispensed by Dispenser #M during the different phases

Approaching from the clinical practice point of view, based on in-clinic experience, the initialization is not a significant problem, since it typically involves only a few doses, and the maintenance staff, responsible for refilling or changing dispensers, often tests the system after the change, using these doses for testing purposes. For that reason, this protocol focuses only on the run-out phase.

In some cases, it was noticed that the run-out characteristics may be influenced by the handrub format. Long run-out is less typical when liquid handrub is used. Figure 14 provides an example where the run-out was measured with the same dispenser (#A) using both liquid and gel handrub.

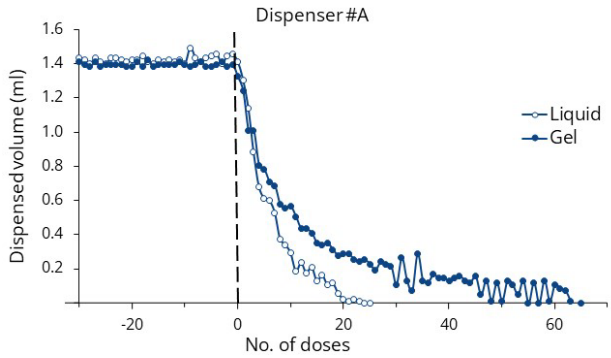

Figure 14

The duration of the run-out phase may be influenced by the format of the handrub. Dispenser #A is a good example of that: the run-out lasted for 22 and 65 doses when liquid and gel formats handrub were used, respectively.

In one case, it was experienced that even run-out had two phases: the gradual decrease in volume, and at one point turned into a sudden decline (Figure 15).

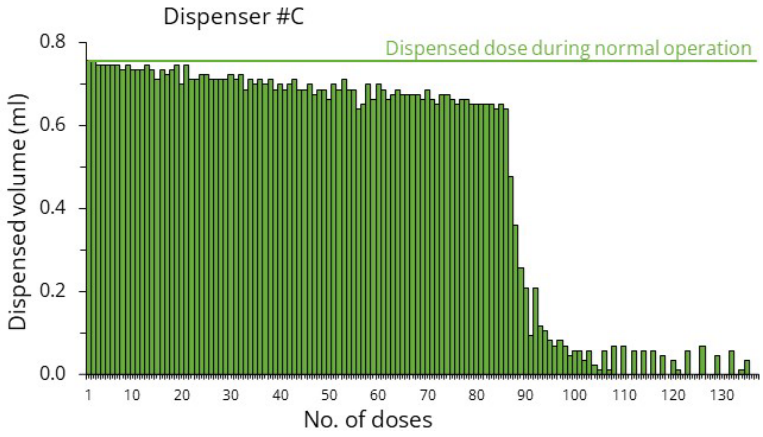

Figure 15

A particular, two phases of run-out: the dispensed volume started to decrease slowly, then turned into a sudden drop. This raises patient safety related quality issues.

4 Discussion

Numerous studies indicate that the amount of handrub is primarily determining the effectiveness of clinical hand hygiene. With lower ABHR volume, the larger part of the hand surface remains uncovered [5, 6]. Generally, it appears that an amount less than 2 ml is not enough to cover the entire surface of a medium-sized hand [7]. The previously mentioned new ISO 23447:2023 standard emphasizes that hand hygiene should be carried out by applying at least 1.5 ml handrub [4]. However, it does not specify the appliable dose (number of strokes) coming from the dispensers. Other large-scale investigation describes that the majority of people use only one dose from a dispenser, regardless of the provided volume [8]. In a dataset of 28 million hand hygiene events, collected by electronic compliance monitoring systems, at 86% of hand hygiene events hospital staff used a single dose (1 stroke/application).

A recent, unpublished study reveals that when healthcare workers were asked about the appropriate handrub volume for a hand hygiene event, a significant number of respondents linked the suitable volume to the operation of the dispenser (e.g., 2 strokes/pushes, 1 squeeze, 1 dose, etc.). That is why it is important to know, and let the users know about the exact amount the dispenser provides, and the factors that can affect the dosing, consecutively determining the quality of the hand hygiene.

If the dispenser cannot provide the expected volume, it can lead to a serious patient safety issue. As mentioned before, even healthcare professionals who frequently use ABHR found it challenging to estimate the actual received volume. Caregivers will not notice if the dispenser provides less volume, but their hand hygiene performance will significantly decline, while providing a false safety illusion.

Our studies had several limitations. We used each dispenser with its own refill, which means the ABHR compositions varied (within the standardizer range). These differences could potentially slightly influence the test results, but this aspect was not examined in our study. Our study included only a limited number of dispensers (though we aimed to select those most frequently used in hospitals), therefore, we cannot claim that our protocols are complete. Additional parameters may also need to be monitored. Testing only 13 dispensers represents a relatively small sample size. Nevertheless, if we observed inconsistencies in dispensing depending on the parameters examined, it suggests that this may be a common issue. To prove this concept, further large-scale and comprehensive investigations would be necessary.

Conclusions

The aim of our research was to establish an evidence-based measurement and assessment protocol for alcohol-based handrub dispensers. The protocol stands both for manual and automatic systems, investigating a wide range of parameters, also tapping into the functionalities of the novel type dispensers, categorized as digital medical devices. Further, a selective applied study was conducted to validate the testing protocol along a range of clinically employed ABHR dispensers.

None of the evaluated dispensers demonstrated superiority along all tested parameters. Provided the complexity of their relations to patient safety it may be acceptable if a dispenser is underperforming in a part of these tests, and some reasonable compromises can be made, or e.g., user education can counterbalance these. Either way, a complete behavioral change shall accompany the introduction of high-quality hand hygiene programs including the focus on volume-awareness of the caregivers [13].

We strongly believe that information regarding dispenser performance should be freely available, and users such as hospitals and infection control professionals must be aware of the performance of the dispensers they are using. For instance, if it is known that the dispenser loses volume over time, but only when it is employed with liquid handrub, this knowledge could influence the ABHR product preference on that particular ward. Wards vary significantly in dispenser usage patterns, maintenance capacity and other factors, making such decision complicated on a facility level. To enable stakeholders to choose the most suitable dispenser for their needs, they should have access to dispenser parameters relevant

to them, and create an institutional hand hygiene policy, as recommended by the ISO 23447 [4].

We hope that this study will prompt large-scale investigations to determine whether all our selected parameters are essential or if additional parameters should be considered. We strongly encourage manufacturers to test their dispensers and transparently communicate their results. The detailed validation protocol outlined here is intended to serve as the bases for a standardized, generalized test protocol in the future.

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