

## Information Technology Tools Employed in Infection Control

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**Abstract**— Hygiene, in general is a key attribute to maintain safety and healthy procedures at various industries, ranging from food processing to medical care. It is linked to human behavior at multiple levels, which means, relevant standards and protocols are often bypassed due to the lack of competence, skill and willingness for compliance. The act of hand hygiene—or hand rubbing, when performed with an alcoholic disinfectant solution—has become a standard practice both in personal hygiene and in the medical and clean site manufacturing domains. However, fundamental problems remain associated with the improper execution of hand hygiene (hand washing and rubbing) that calls for a technology-advanced solution. Technology-induced behavioral change is a recent emerging paradigm, where ICT tools properly integrated to the daily workflow of humans can significantly alter their routine behavior. The trend is now clearly visible in many domains of health care, and this paper aims to provide a general overview of the cutting edge technological solutions addressing the urging need of infection control.

**Keywords**—hand disinfection, objective evaluation of hand rubbing, hand hygiene control

### I. INTRODUCTION

Healthcare-Associated Infections (HAI) are one of the most serious healthcare issues in the Western world, the 4<sup>th</sup> leading cause of death in the USA [1], as even gloves may only reduce contamination by 70–80% [2]. Due to the rise of antibiotic resistant stems, such as Methicillin-Resistant *Staphylococcus Aureus* (MRSA), *Clostridium difficile*, Drug-resistant *Streptococcus pneumonia* infections remain a lethal threat [3]. An earlier publication from a UK hospital showed that “After contact with patient’s environment, 10% of Health Care Workers (HCW) tested positive for MRSA on their fingertips, of whom 41% had used hand rubs” [4]. Eradicating HAI is an unmet medical/humanitarian need, and the lack of success in controlling it so far underlines that it requires very complex and integrated solution to tackle the problem. Recent studies clearly showed that training and

education only cannot solve this problem, advanced tools must be employed [5].

According to the World Health Organization’s (WHO) estimates, HAI results in 1.4m cases a day globally, leading to a quarter of a million unnecessary deaths a year in the developed countries alone [6]. In the USA, according to the Centers for Disease Control and Prevention (CDC), there are more than 2 million infections [7] and more than 99,000 infection-related deaths each year [8]. If HAI occurs, it extends the hospital stay by an average 16 days, and the mortality rates increase to 5 times higher [9].

Despite all the previous efforts—including governmental campaigns and global educational programs—Western hospitals still have a 10% average HAI ratio [6]. Newest US reports show a gradual decrease in overall hospital-acquired complications, yet the numbers are still over 13% [10]. Hospital Infections Disclosure Act (HIDA) HIDA was implemented in 2007 and currently 24 states have adopted legislation requiring public reporting of hospital infection rates and 19 have adopted legislation regarding the reporting of hospital infection rates. Regular hand washing has already been proved through numerous peer reviewed studies to be efficient to reduce the incidence of diseases, thus improving the quality of life [11].

### II. THE COST OF POOR HAND HYGIENE

Costs for HAI in Europe are approximately \$9.3 billion annually [12]. The most common type, central line-associated bloodstream infections were found to be the most costly HAIs at over \$45k extra cost per incidence [13]. Pennsylvania State in the US reported a total of 11,500 infections in 2005 that accounted for over \$2bn extra costs [14]. HAI is estimated to cost \$96bn–\$147bn each year to the US economy [15]. It is estimated that in the EU an average 500 bed hospital loses \$1.87m on infections annually [16].

According to a very conservative WHO estimation, effective hand disinfection has shown to decrease HAI by at

least 30%, which may manifest in an annual saving of €18bn in the Western world. Up to 66% of certain types of HAI are caused by improper hand hygiene [17]. A recent survey found that reported direct cost savings on avoided HAI cases accounted for hand hygiene ranged from \$32K–476K for various hospitals [18].

Compliance of the medical staff to hand hygiene is only 60% even at well-reputed institutions, while the average reported incidence of nosocomial infections is 7.1% in the Western world. Governments and insurance companies are now explicitly charging the hospitals for the avoidable costs of HAI. Since Oct. 1, 2008, the U.S. Centers for Medicare and Medicaid Services no longer provide reimbursement for cases with a diagnosis of HAI [19]. Further, in the UK, NHS Quality Premium payments to Clinical Commissioning Groups (CCGs) are linked to HAI prevention efforts (12.5% of the *premium* in 2013-14) [20].

### III. BEST PRACTICES IN HAND HYGIENE FOR INFECTION CONTROL

Alcohol-based hand rubs are recognized as the most effective tools to prevent HAI [21], therefore the use of them became a general standard and a European Norm [22]. The same methods apply to the biotech and clean industry, enforced by the Good Manufacturing Practice (GMP) [23].

First, the WHO defined the “Five Moments for Hand Hygiene” as part of the WHO Guidelines on Hand Hygiene in Health Care to add value to any hand hygiene improvement strategy. It defines the key moments for hand hygiene (compliance), overcoming misleading language and complicated descriptions, presenting a unified vision and promoting a strong sense of ownership of HCWs [24].

The WHO six-step hand washing procedure (Figure 1) is the globally recognized protocol for clean hands [25]. It can be found in many official recommendations and guidelines. By applying this protocol, it becomes easier to remember cleaning the whole hand surface efficiently, yet only in 8% of the cases the protocol is followed thoroughly [26]. Moreover, 27% of people fail to achieve a complete coverage of their hands even when they perform the 6-steps, leading to potential infections [27]. Some groups therefore promote the “Self-responsible application of hand rubs”, trusting HWCs to cover the most critical areas [28].

Rigorous education and promotion campaign at the National University Health System Singapore resulted in the growth of compliance in their intensive care units from 38% to 69% in 3 years, while MRSA acquisition ratio dropped from 10.1% to 1.1% [29]. Another recent report from Vanderbilt University revealed that over 5 years of continuous education and training, average compliance ratio (only considering before/after patient) increased from 58% to

96.6%, while urinary tract infections dropped by 33%, pneumonia-linked ventilation infections by 61% and central-line associated bloodstream infections by 80%, respectively [30]. This data show the difficulty to implement correct hand hygiene practices in a busy environment, where human factors play a huge role.



Figure 1 WHO's world renowned 6-step hand hygiene protocol—a global standard.

Source: WHO, <http://www.who.int/gpsc/en/>

The two most important performance indicators of hand hygiene are monitoring of the *event compliance* and the *technique*. In other words, it has to be monitored that:

- 1) employees always rub their hands when it is recommended by policy: event compliance;
- 2) they always do it the right way: technique.

Traditionally, hand hygiene compliance—both event and technique—has been assessed by direct human observation method (current WHO recommendation). It has never been considered to be statistically trusted [31], and has serious drawbacks:

- 1) observer-distortion (Hawthorne) effect [32]—people tend to behave better if they are visually controlled,
- 2) high cost,
- 3) timeliness,
- 4) subjectivity of the observer,
- 5) poor statistical power due to the low sample size.

### IV. HAND HYGIENE CONTROL AND MONITORING

HCW's adherence to hand hygiene traditionally has been well below the required level. In the past 10 years, several

commercial products and approaches have been developed to increase it. It is generally accepted that a healthy balance is required between compliance monitoring and education of the technique. Many companies started to develop ICT tools to support HCWs, having realized the importance of hand hygiene linked to HAI.

- 1) Software solutions exist to support the registration of hand washing events, however, these require manual data input.
- 2) Automated compliance monitoring systems have been developed, tracking the spatial movement of the staff and linking it to hand hygiene events.
- 3) There are educational tools using UV-reflective gels to demonstrate hand rub use through removing the reflective material. Occasionally, hand washing quality is checked under UV lighting, but only verified by the naked eye.
- 4) Newest technologies address the issue of objective monitoring and assessment of the hand rubbing technique.

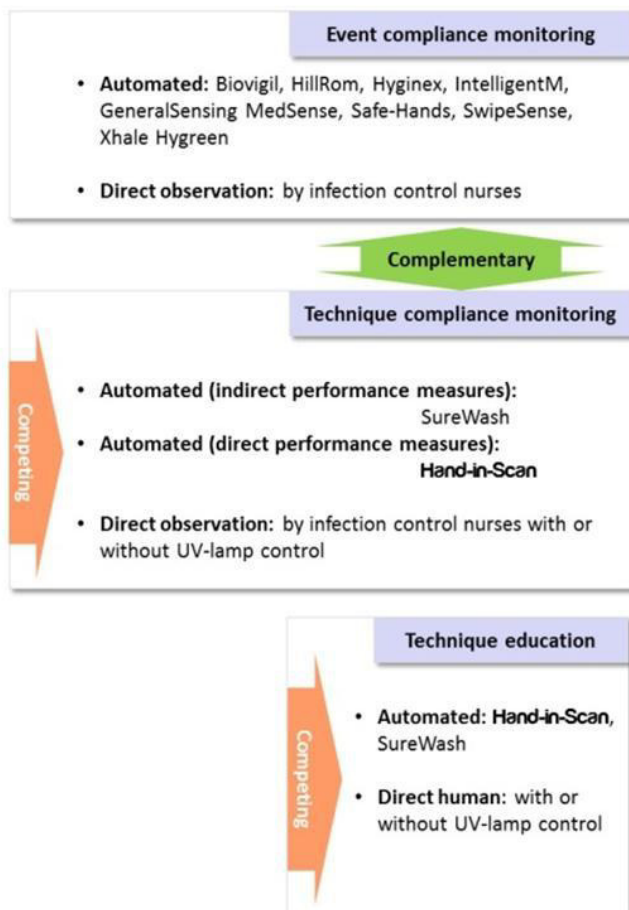


Figure 2 Technology segments of electronic hand hygiene control and support.

#### A. Automated (electronic) observation:

Technology is coming to the rescue with computerized performance indicators for measuring improvement in HCWs' adherence to hand hygiene protocols. Classically, only the overall hand rub consumption is monitored. From 2010 and on, hand hygiene solution manufacturers in healthcare have grown tremendously. Several developed their own hand hygiene monitoring system, or training courses based on the WHO's guidelines and CDC recommendation [33]. Many of these products are based on the concept of monitoring the "Point of Care" (PoC) for every patient, meaning that an electronic sensor is placed in the wardroom, which communicates with the worker's badge in order to remind them to wash hands when entering or leaving the patient's surrounding (Fig. 3). Electronic surveillance has many options; the key feature is to be able to automatically identify the location and the motion of the HWC relative to the POC. This can be achieved employing:

- RFID tags
- US identification
- RF tracking
- Video monitoring.

Table 1. summarizes most of these systems identified (solutions publicly known as of now), along with their major features. The various features enable different level of technology-integration. Automated data collection and database recording are considered to be the most important features of these systems.

##### i) Event compliance monitoring

It is not the mere number of hand washing events per day ("frequency") that is only important but also *when (and how)* HCW wash their hands. The number of opportunities to perform hand hygiene (as determined by WHO's 5-moments



Figure 3 Examples of electronic hand hygiene systems: HyGreen, Proventix nGage and SureWash.

and healthcare-facility policies and the number of coinciding events that occur) is the foundational element to be measured, yet many devices focus on a more simple approach, e.g., POC on/out measurement [32]. It has been reported that equipping one patient care using with electronic sensors for consumption monitoring may cost up to \$40,000 [34]. These monitoring systems, such as IntelligentM ([www.higenx.com/](http://www.higenx.com/)), HigenX ([www.higenx.com/](http://www.higenx.com/)), Dubmed ([www.newswiretoday.com/news/141062](http://www.newswiretoday.com/news/141062)), i360hygiene ([www.i360hygiene.com](http://www.i360hygiene.com)) or HandGiene ([www.hpnonline.com/inside/2014-03/1403-IP-HHSurveillance.html](http://www.hpnonline.com/inside/2014-03/1403-IP-HHSurveillance.html)) have the ability to record the hand hygiene events, monitoring only compliance and not the quality. Studies showed that raising HH compliance among healthcare workers results in a 10-80% decrease in HAI cases. For instance, using Ecolab's Proventix nGage (<http://proventix.com/ngage>) system for a 7-month trial period, the Princeton Baptist Medical Center of Birmingham reported a decrease of 159 patient days and reduced hospital net losses of over \$133,386, reflected on just 2,652 patient admissions [34]. A more sophisticated system has been developed by using alcohol sensors. The US based company's products HyGreen ([hygreen.com](http://hygreen.com)) and Biovigil ([www.biovigilsystems.com](http://www.biovigilsystems.com)) have extended the PoC concept: a wall-mounted sensor or a badge has to sense alcohol prior to entering a patient's area, which is isolated with a proximity sensor located on the top of the bed, or at the doorway. If alcohol is not present when indicated, the worker's badge vibrates, as a reminder function. However, this system only detects the presence of alcohol but not the quality of the hand wash. Recent reports revealed that after 6 months of installment, the usage of these monitoring technologies is extremely low, therefore smarter workflow integration methods are required.

## ii) Technique monitoring

Most companies focus on indirect performance measures, like hand wash duration or assessment via direct video monitoring [30]. Technologies that enable this direct observation and try to make it more "objective" are e.g., the handheld UV lamps used with UV-dyed hand rub. These have been on the market for more than 30 years, but have not made any revolutionary effect in hand hygiene, since they could not solve the other inherent problems of direct observation (Hawthorne effect, problem of the power-gap, etc.). Companies in this field are: Glow Germ (<http://hand-hygiene.com>), Anios (<http://www.securimed.fr/caisson-pedagogique-9836.html>), Dermalux ([www.disinfection.ch/hygieneschulungen/hygieneschulungen.htm](http://www.disinfection.ch/hygieneschulungen/hygieneschulungen.htm)), AllPax Derma LiteCheck Box ([www.allpax.de/product\\_info.php/info/p9620\\_Derma-LiteCheck--Box.html](http://www.allpax.de/product_info.php/info/p9620_Derma-LiteCheck--Box.html)).

SureWash (Glanta Ltd, IR) was the first product on the market using video stream to evaluate hand washing performance. Its primary focus is educational use, the system helps the user performing the WHO 6-step procedure while measuring the dry-run performance (no hand rub used) with real-time video recording and stream processing. The system is overviewed by the infection control specialist, and can be placed into various departments of the hospital for periodic training.

Hand-in-Scan (HandInScan Kft.) is a recent innovation of a Hungarian start-up company, employing digital imaging and image processing to instantaneously identify any missed regions on the hands. Hand-in-Scan objectively evaluates and records every hand disinfection event per person, and is able to generate statistics and proper reporting to the management (Fig. 4). Implementing the experiential learning theory, the user learns the correct hand washing technique while performing it in front of the device. Hand-in-Scan provides immediate feedback on hand washing performance, resulting in healthcare worker's hand hygiene compliance and technique improvement. The system eliminates the blame-factor, and helps to avoid the boss-subordinate conflict [35].



Figure 4 The Hand-in-Scan Medical Trainer hand hygiene monitoring and control system.

## V. DISCUSSION

An ideal hand hygiene efficiency system should contain both event compliance and technique monitoring. In this sense, the field is really in its infancy yet. Almost all monitoring systems listed above primarily and only focus on event compliance, checking on the occurrence and frequency of hand rubbing, but not the quality. Understandably, if the alcoholic solution is not applied correctly, its effectiveness remains low. There are only two companies approaching the problem with more direct (hand washing technique)



performance measurement, the SureWash educational system and Hand-in-Scan.

All these systems have great importance in the future of infection control, since they generate digital data, and make measurable aspects of hand hygiene impossible to adequately monitor before. These new databases enable researchers to draw a better profile on infections, how they spread, transmit and carry on, while the systems behind are emphasizing the importance of self-responsibility of HCW. Technology does induce behavioral change.

## VI. CONCLUSIONS

Traditional, visual observation of the health care workers requires extensive human resources and is not effective. There is a global trend to develop hand hygiene control systems with different approaches, to foster improvement in safe care. The paper identified the main technological directions, systems and concepts for hand sterilization and hand sterilization checking. The list includes all companies spotted, currently selling or developing a solution for hand hygiene control. This field deserves attention from the biomedical engineering community, since the emerging electronic/automated platforms open space for evidence-based medicine in infection control as well.

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Table 1. Complete list of hand hygiene monitoring and control systems.

| System name                      | Partnership                | Immediate corrective action | Educational use | Recording the HH event | Reminder function | Integration to Hospital Information System | User feedback | Feedback to the patient | Regular reporting | Evaluation of technique |
|----------------------------------|----------------------------|-----------------------------|-----------------|------------------------|-------------------|--|---------------|-------------------------|-------------------|-------------------------|
| 3M Clean-Trace                   |                            | X                           | X               |                        |                   |  | X             |                         |                   |                         |
| AccuTrack                        |                            |                             | X               | X                      |                   |  | X             |                         |                   |                         |
| ANIOS                            |                            | X                           | X               |                        |                   |  | X             |                         |                   |                         |
| Arista                           |                            |                             |                 | X                      |                   |  |               |                         | X                 |                         |
| Arrowsight                       |                            | X                           |                 | X                      |                   | X  | X             |                         |                   |                         |
| BioVigil monitoring              |                            | X                           |                 | X                      | X                 | X  |               | X                       |                   |                         |
| Brevis GlitterBug Maxi View Box  |                            | X                           | X               |                        |                   |  |               | X                       |                   |                         |
| DaRo                             |                            | X                           |                 |                        |                   |  | X             |                         |                   |                         |
| DEB DebMed GMS                   |                            |                             |                 | X                      |                   |  |               |                         |                   |                         |
| Derma LiteCheck box              |                            | X                           | X               |                        |                   |  | X             |                         |                   |                         |
| Dermalux Box Checkbox Multimedia |                            | X                           | X               |                        |                   |  | X             |                         |                   |                         |
| Ekahau Inc. HH Monitoring        |                            |                             |                 | X                      | X                 |  |               |                         |                   |                         |
| Ephygie Hand                     |                            |                             |                 | X                      |                   | X  |               |                         | X                 |                         |
| Glo Germ prod.                   |                            |                             | X               |                        |                   |  |               |                         |                   |                         |
| Glowshop                         |                            | X                           |                 |                        |                   |  | X             |                         |                   |                         |
| Glowtech                         |                            | X                           | X               |                        |                   |  |               | X                       |                   |                         |
| GOJO                             | Hill-room, Purell & Provon |                             |                 | X                      |                   | X  |               |                         | monthly           |                         |
| hand giene corp                  |                            | X                           | X               | X                      | X                 | X  |               | X                       |                   |                         |
| Hand-in-Scan                     |                            | X                           | X               | X                      | X                 | X  | X             | X                       | X                 | X                       |
| Handy audit                      |                            |                             |                 | X                      |                   |  |               |                         | X                 |                         |
| Hangenix                         |                            | X                           |                 | X                      | X                 |  |               |                         | X                 |                         |
| HigenX                           |                            |                             |                 | X                      | X                 |  |               |                         | monthly           |                         |
| Hill-rom                         | GOJO, Ecolab               | X                           | X               | X                      | X                 | X  |               |                         | monthly           |                         |
| HygenX                           |                            |                             |                 | X                      | X                 | X  |               |                         | X                 |                         |
| i360 hygiene                     | Surewash                   |                             |                 | X                      | X                 |  | X             | X                       |                   |                         |
| IntelligentM                     |                            |                             |                 | X                      | X                 | X  |               | X                       | monthly           |                         |
| Proventix nGage                  |                            |                             |                 | X                      | X                 | X  |               | X                       |                   |                         |
| Semmelweis Hand Hygienom.        |                            |                             |                 | X                      |                   |  |               |                         |                   |                         |
| Sterilogy LLC                    |                            |                             |                 | X                      |                   |  |               | X                       | X                 |                         |
| Surewash                         | i360 hygiene               |                             | X               |                        |                   |  |               |                         |                   | x                       |
| SwipeSense                       |                            |                             |                 | X                      |                   |  |               | X                       | X                 |                         |
| Xhale Inc. Hygreen               |                            | X                           |                 | X                      | X                 | X  | X             | X                       |                   |                         |