Review of technologies available to improve hand hygiene compliance – are they fit for purpose?

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Abstract

Hand hygiene has been empirically proven to prevent cross-transmission of infection, which has led to the development of global guidelines such as the World Health Organization's 'My 5 Moments for Hand Hygiene.' Because of the relatively recent launch of these guidelines (2009) technology designed to assist in measuring hand hygiene compliance appears not to fully acknowledge the influence of the WHO 5 Moments for hand hygiene. Consequently, they may not be fit for purpose (FFP). This paper uses a review of the literature on current hand hygiene technology to assess the extent to which these are FFP based on these global guidelines. The results show that there are a variety of technologies available to assist with the monitoring and measurement of hand hygiene levels. However, none appear to explicitly achieve detection of all WHO 5 Moments for hand hygiene, limiting their effectiveness. The authors conclude that a systems approach offers a potential aid for developers aspiring to meet domain specific FFP requirements. Human factors may help guide such developments to meet user and context specific needs.

Introduction

Human factors (HF) can be defined as understanding human behaviour in purposeful interacting systems and the application of that understanding in the context of the real setting (Wilson, 2000). This systems-oriented perspective (Wilson, 2014) highlights the interaction of people and environments and provides an interdisciplinary and multidisciplinary theoretical understanding of such interactions (Wilson, 2000).

Within patient safety these principles are widely used to analyse system errors within surgery (Catchpole et al, 2008), medical device design (Lin et al, 2001) as well as developing conceptual frameworks

to guide nurses' workload (Carayon and Gurses, 2005). The aim of an HF approach is to ensure something is fit for purpose (FFP) thereby enhancing efficiency and safety.

A key area of patient safety is hand hygiene, empirically proven to prevent cross-transmission of infection (e.g. Bauer et al, 1990; El Shafie et al, 2003). This has led to the development of the evidence-based WHO 5 Moments for hand hygiene (Sax et al, 2007). These guidelines have been established as a successful, user-centered and evidence-based approach for considering hand hygiene within a patient care scenario (Sax et al, 2012). Hand hygiene is recommended at five specific moments to prevent cross-transmission of contamination, reducing risk of healthcare associated infection.

The current gold standard for measuring hand hygiene compliance is direct observation (WHO, 2009). However this is resource intensive and can lead to changes in healthcare professional behaviour (e.g. Eckmanns et al, 2006; Kohli et al, 2009). Feedback of compliance data has been shown to improve hand hygiene performance, for example using purpose designed audit tools (e.g. Health Protection Scotland, 2009) and with multi-modal interventions (e.g. Pessoa-Silva et al, 2007; Pittet et al, 2000). Development of technology to assist in measuring hand hygiene compliance (e.g. video surveillance; Ghosh et al, 2012; RFID systems; Sahud et al, 2012; ABHR sensing badges; Edmond et al, 2010) appears to offer an alternative to observation; however questions arise about their FFP.

Aim

This paper asks if hand hygiene measurement technology is FFP using the WHO 5 Moments as the desired patient safety standard. FFP technologies may enable and encourage adherence to these evidence-based guidelines. The paper reviews current technologies described in the literature based on their ability to monitor, measure and provide feedback at each of the WHO 5 Moments.

Table 1. Word sets used for literature search

Set 1 Hand Hygiene:	Hand hygiene or Handwashing or Handrubbing or Hand Rubbing or Hand antisepsis or Hand decontamination or Hand degerming or Hand cleansing or Hand disinfection
Set 2 Technology:	Electronic technology or hand hygiene technology
Set 3 WHO 5 Moments:	My 5 Moments of Hand Hygiene or WHO 5 Moments

Fit for purpose criteria	Technologies awarded a "1" if they:
Monitoring	<ul style="list-style-type: none"> • Possess ability to <i>Monitor</i> healthcare professional hand hygiene • Key question: <i>can the technology detect whether hand hygiene is being performed?</i>
Measurement	<ul style="list-style-type: none"> • Possess ability to <i>Measure</i> healthcare professional hand hygiene • Key question: <i>can the technology provide information about hand hygiene performed?</i>
Feedback	<ul style="list-style-type: none"> • Possess ability to provide feedback about healthcare professional hand hygiene • Feedback can be: <i>Real-Time (e.g. beeping, flashing, vibrating prompts) and/or through data reporting</i>
WHO 5 Moments	<p>A further '1' can be awarded for each of the WHO 5 Moments the technology can detect hand hygiene occurring directly:</p> <ol style="list-style-type: none"> 1. Before Touching a Patient: <i>Points to consider: Is technology able to operate within the Patient Zone? If the technology currently operates at entry/exit is there potential for it to be tested within a Patient Zone setting e.g. reducing the distance between detection area and likely patient contact point?</i> 2. Before Clean/Asptic Procedure <i>Points to consider: Is the technology able to detect that a clean/aseptic procedure is about to occur, therefore able to accurately record ensuing hand hygiene behaviour (compliance/non-compliance) or provide prompt?</i> 3. After Body Fluid exposure risk <i>Points to consider: Is the technology able to detect when a procedure has involved bodily fluids, even if hand surfaces have not had direct contact?</i> 4. After Touching a Patient <i>Points to consider: Is technology able to operate within the Patient Zone? If the technology currently operates at entry/exit is there potential for it to be tested within a Patient Zone setting e.g. reducing the distance between detection area and likely Patient contact point?</i> 5. After Touching Patient surroundings <i>Points to consider: Is technology able to operate within the Patient Zone? Can the technology detect interaction between the hand surface of a healthcare professional and surfaces within the Patient Zone?</i>

Figure 1. Fit for purpose matrix which provided scoring criteria and guidance for reviewing technologies based on their ability to monitor, measure and provide feedback about hand hygiene at each of the WHO 5 Moments

Method

Article selection

Article selection took place from November 2011 to January 2013. Six databases covering a multi-disciplinary scope (Medicine, Ergonomics, Engineering, General Knowledge) were used along with expert consultation and internet searches. Three word sets were used to find articles (Table 1), based on the topics of hand hygiene, technology and the WHO 5 Moments.

Hand hygiene literature shows varied nomenclature for the practice of decontamination of hands, thus key texts (WHO, 2009; MeSH terms) were reviewed to provide search terms for word set 1. Rather than searching for specific technologies linked to hand hygiene technology (e.g. radio-frequency infra-red, RFID) generic terms were used for word set 2 to allow full exploration of the field. The purpose of the literature review was to explore whether current hand hygiene technologies could help with detection of the WHO 5 Moments. Therefore this global standard was explicitly used as a search term for word set 3.

Words within sets were separated with the operator 'OR', with sets conjoined with the operator 'AND'. Databases were date limited '2009 to Current Date', to reflect the introduction of the WHO 5 Moments, with the default language for returned articles set to English.

Articles mentioning any electronic technology being applied to a healthcare setting to monitor, measure or provide feedback on hand hygiene performance were selected for further analysis. A finite list of technologies was identified from the returned articles, which were assessed for FFP using a bespoke Matrix (Figure 1).

Review process

The matrix was developed to allow each technology to be rated on specific aspects of FFP: ability to monitor, measure and provide feedback around each of the WHO 5 Moments. These FFP capabilities were chosen to represent functions that would be required to provide an effective, reliable and potential alternative to direct observation.

A scorecard approach was used for analysis. Each technology scored '1' per capability it could achieve, the maximum score being '8' and the minimum score being '0'. Assessment of technologies identified through the database review was carried out independently by two reviewers, using the criteria and guidance notes provided in the matrix (Figure 1).

If a technology explicitly mentioned being able to detect hand hygiene it scored a '1' for monitoring. Being able to provide data about the hand hygiene, including frequency, showed the capability to measure and provide feedback. To achieve a '1' for each of the WHO 5 Moments a technology had to demonstrate the ability to detect hand hygiene at clinical activities representing these Moments. In accordance with Boyce (2011) room entry and exit were considered a proxy measure for Moments 1, 4 and 5, if they offered potential for detection to be narrowed to the Patient Zone. Technologies that were based on 'fixed' areas, such as communal taps, were deemed unable to offer potential to detect Moments 1, 4 and 5. After the initial review eight discrepancies between reviewer scores were recorded. These were resolved through discussion and joint review, based on the FFP guidance notes and criteria. This clarified the term feedback to ensure

Figure 2. Flow-diagram of inclusion and exclusion decisions during the review process resulting in 19 unique technologies being assessed by matrix scorecard

Table 2. Number of technologies possessing each fit for purpose (FFP) capability

FFP capability	No. of technologies possessing capability
Monitor	19
Measure	19
Feedback	19
Moment 1: Before Touching a Patient	15
Moment 2: Before Clean/Aseptic Procedure	0
Moment 3: After Body Fluid exposure risk	0
Moment 4: After Touching a Patient	14
Moment 5: After Touching Patient surroundings	3

both reviewers scored a '1' for technologies providing real-time feedback (e.g. visual/audial prompts) as well as for those providing recorded data.

Results

The review from the six databases returned 193 articles, 178 were rejected as duplicates or as non-relevant (e.g. technology and/or hand hygiene not being the subject of the paper; being systematic review papers). Reviewers examined the remaining 15 articles for relevance: five were rejected due to non-relevance. A total of 10 articles, published between 2009 and 2012, were retained for full analysis, containing reference to seven unique technologies. Additional searching in January 2013, using Google and consultation with experts, led to 12 further technologies being identified and reviewed (Figure 2). These technologies featured in articles published between 2010 and 2012, or on websites updated during 2012.

The review highlighted 19 unique technologies relating to hand hygiene measurement within health care. The application of the matrix scorecard found none were fully FFP in their ability to monitor, measure and provide feedback at all the WHO 5 Moments (Table 2).

Discussion

The 19 technologies revealed by this review were diverse in nature (Table 3). Technology mechanisms for monitoring included RFID, infrared detection, wireless networks and video monitoring. The majority ($n=10$) employed a 'badge' system worn by healthcare professionals, of which half could provide 'prompts' to perform hand hygiene when required by system rules (e.g. room entry/exit, entering Patient Zone). For the majority ($n=12$) details regarding technical specification, system capabilities and testing were limited, perhaps due to Intellectual Property concerns.

Technology monitoring at Moments 2 and 3

Moment 2 requires hand hygiene to be performed 'Before Clean/Aseptic Procedure'. Therefore any technology must be able to predict the imminent occurrence of a clinical activity requiring hand hygiene at this Moment in order to capture behaviour, and/or deliver any necessary 'prompt'. Currently such behavior-predicting technologies do not exist, and may never be a feasible option for the clinical environment. Should such innovations occur the question of whether healthcare professionals would engage with 'mind-reading' technologies is doubtful, considering existing hesitancy towards current hand hygiene technologies (Ellingson et al. 2011; Dawson, 2014).

Moment 3 requires hand hygiene to be performed 'After Body Fluid exposure risk'. Various patient care duties may characterise Moment 3 including interaction with bodily fluids. Crucially these do not have to involve the visible soiling of hands (Sax et al. 2007). Therefore technologies able to detect the physical presence of fluids (e.g. fluid sensors) would not be sufficient. It is the risk of hand contamination that is the driver behind Moment 3, rather than only being applied to situations where physical soiling has occurred. The challenge for technology is the detection of such a risk having occurred.

Further focus from technology developers surrounding these two Moments may be futile, while direct observation continues to provide a suitable alternative. Indeed, Boyce (2011) concurs with the output of this review, suggesting that technology, with further work, offers most potential for Moments 1, 4 and 5.

Technology monitoring at Moments 1, 4 and 5

Of the 19 technologies three were able to detect Moments 1, 4 and 5 (Table 3: ref numbers 1, 18, 17). Fourteen were able to provide monitoring, measurement and feedback at Moments 1 and 4. More were

Table 3. Brief overview of the 19 unique technologies returned from database (DB) and non-database (NDB) sources and their fit for purpose (FFP) capabilities

Ref No.	Source	Paper	Brief description of technology	FFP capability possessed			WHO Moment					Total FFP Score (out of 19)
				Monitor	Measure	Feedback	1	2	3	4	5	
1	DB	'Badge' Technologies Boscart et al (2009)	Infrared (IF) badges, recording and prompting Patient Zone hand hygiene	1	1	1	1	0	0	1	1	6
2	NDB	Ferenc (2012)	RFID/wireless badges allow prompting upon approaching Patient Zone.	1	1	1	1	0	0	1	0	5
3	NDB	Anon (2011)	RFID badges allowing prompting upon approaching Patient Zone.	1	1	1	0	0	0	0	0	3
4	DB	Edmond et al (2010)	Badges detect alcohol in gel/soap, LED for visual feedback (entry/exit).	1	1	1	1	0	0	1	0	5
5	NDB	Hygenix	Bracelet wirelessly interacts with tap/soap dispensers, records frequency and duration. Also prompts (entry/exit).	1	1	1	1	0	0	1	0	5
6	DB	Cheng et al (2011)	Radio frequency (RF) badges detect hand hygiene at WHO Moments 1 and 4.	1	1	1	1	0	0	1	0	5
7	DB	Polgreen et al (2010)	Badges using MOTES (entry/exit).	1	1	1	1	0	0	1	0	5
8	DB	Sahud et al (2012)	RF badges (entry/exit).	1	1	1	1	0	0	1	0	5
9	NDB	Centrak	IF/wireless badges. Possible additions: prompting and real time location system (RTLS) (entry/exit).	1	1	1	1	0	0	1	0	5
10	NDB	Jeppsson (2011)	RFID badges interact with dispensers to deliver tailored feedback.	1	1	1	1	0	0	0	0	4
11	DB	'Video' technologies Armellino et al (2012)	Video technology using remote auditors.	1	1	1	1	0	0	1	0	5
12	NDB	Surewash	Video technology. Feedback on frequency, quality of sink hand hygiene technique.	1	1	1	0	0	0	0	0	3
13	NDB	Sealed Air	'Smart Video' technology stores images/film of when individuals are not wearing correct personal protective equipment when expected (currently food industry specific).	1	1	1	1	0	0	1	0	5
14	DB	Other measurement technologies Do (2009)	Review of 'Smart Room' to enable hand hygiene: positioned monitors and lights, RFID for monitoring and feedback.	1	1	1	1	0	0	1	0	5
15	NDB	Anon (2012)	Hand hygiene monitored through tap use, quality judged by length of wash.	1	1	1	0	0	0	0	0	3
16	NDB	Cantrell (2012)	Dispenser usage compared to expected hand hygiene rates based on validated context-specific WHO 5 Moments benchmark.	1	1	1	0	0	0	0	0	3
17	NDB	Lorenzi (2011)	Dispenser system using RTLS to record usage in specific units (entry/exit).	1	1	1	1	0	0	1	1	6
18	NDB	Czyzewski (2011)	Thermal detection senses activity within defined zones and compares with expected activity: already being trialled within NHS settings.	1	1	1	1	0	0	1	1	6
19	NDB	Hlady et al (2010)	Electronic auditing tool designed for greater accuracy/efficiency than manual auditing.	1	1	1	1	0	0	1	0	5
			Total number of technologies scoring a '1' (out of 19)	19	19	19	15	0	0	14	3

Figure 3. A systems way of considering technology for hand hygiene monitoring. Adapted from Vicente (2006)

based at a room entry/exit level, rather than specifically around the conceptual Patient Zone (8:6 ratio).

Technology monitoring at Moment 5

No technologies made reference to the ability to measure/detect Moment 5. However, three technologies have the potential capability to track healthcare professional activities within the Patient Zone. Therefore, it was determined that inferences about potential 'Contact with Patient Environment' could be drawn from hand hygiene data collected.

Based on environmental contamination evidence (Bhalla et al, 2004; Otter et al, 2006), and evidence that hands can become contaminated through activities involving routine contact with objects within the patient environment (Tenorio et al, 2001) the authors feel this area would benefit from attention by technology developers.

Technology feedback data at Moments 1, 4 and 5

Technologies able to detect hand hygiene at Moments 1 and 4 ($n=14$), and perceived to have potential for Moment 5 ($n=3$), were all able to monitor, measure and provide feedback. This allows healthcare professionals to collect data about performance, and provides the opportunity for real-time reminders to be given for individuals to perform hand hygiene as required.

Systems with the ability to provide individual data about specific moments of patient care allow analysis of areas of strengths and weaknesses. Measuring performance based upon recognisable standards can provide meaningful feedback, thereby allowing a continuous improvement approach. Interventions can then be targeted at specific WHO Moments with lower hand hygiene compliance.

A combination approach to hand hygiene measurement: technology and direct observation

Currently the WHO recommend direct observation as the gold standard for hand hygiene measurement. However, this method is open to limitation, including labour intensiveness, observational bias and sample size (Haas and Larson, 2007; Gould et al, 2007).

An advantage of technologies such as infrared and radio-frequency (Boyce, 2011, Table 3, p. 1022, provides useful summary) is their ability to monitor 'behind the curtain'. This could negate an often cited problem of direct observation whereby opportunities to observe healthcare professional behaviour are missed/interrupted by patient care taking place out of sight of the observer (van de Mortel and Murgo, 2006). Sensory technology, once passed by hospital regulators, is without such restraints. Therefore data can continue to be collected undisturbed. Cheng et al (2011) suggest that technology

may significantly reduce observation effects, with their comparison of electronic and manual surveillance demonstrating measured compliance levels 2.8 times higher for manual observation sessions than for electronic surveillance only sessions.

Once confident in the ability of technologies to capture WHO Moments 1, 4 and 5, resources could be reassigned to observe Moments 2 and 3. These two Moments appear to have a link to a higher automatic recourse to hand hygiene (Dawson, 2013) and the 24/7 level of monitoring and immediate feedback provided by technological systems may not be as useful as for Moments 1, 4 and 5, which appear to require additional education and training.

Boyce (2011) suggests that Moments 1, 4 and 5 alone may be responsible for approximately 80% of all hand hygiene opportunities within clinical care. Therefore allocation of electronic surveillance specifically designed to capture data from these areas may represent a significant benefit to those aiming to improve hand hygiene overall.

Although no reviewed technologies proved FFP for all 5 WHO Moments, this does not necessarily infer that electronic monitoring does not have a place. With the acknowledged limitations of the observational method, technology may offer accurate, relevant data for healthcare professionals to improve their hand hygiene compliance. Considering this, the authors suggest technology be seen as an aid to hand hygiene measurement, rather than manual and technological measurement being seen as mutually exclusive methods.

Recommendations for developing technology: a systems approach

In order to ensure that the FFO of such technologies is increased, HF could play a fundamental role in their development. By using an HF systems approach, suitable solutions may be formed, developed and subsequently tested. Wilson (2014) cites Rouse (2010) to suggest that elements of systems approaches within the HF domain are concerned with understanding, designing and supporting human roles and performance in complex systems. Hand hygiene is a complex behaviour influenced by innate behaviour, job tasks and pressures, and the physical environment. Use of conceptual models may help frame problem-solution thinking more clearly to accommodate these factors. The Human-Tech Ladder (Vicente, 2006), is one such conceptual road map. This provides a means to:

'Develop a good understanding of the principles that govern human behaviour [and] Adopt a context-specific, problem driven approach' (Vicente, 2006, pp. 52–3).

This conceptual framing would allow each component of the technology to be considered in relation to the variety of influencing variables

associated with hand hygiene compliance. This is briefly touched upon here, but facilitates problem-solution thinking that may help ensure that future technology is FFP and used in areas of most effect, here proposed as Moments 1, 4 and 5 (Figure 3).

The example of this thinking presented in Figure 3 would help to ensure technology is not only FFP from a practical 'physical' sense, but would help ensure that issues such as domain specific usage and acceptance are addressed. The latter is of particular significance in light of findings by Dawson (2014) and Ellingson et al (2011), who reported negative perceptions from healthcare professionals on technology owing to the perceived 'Big Brother' culture. Consideration of 'Team' and 'Psychological' components may enable further research at this domain specific level, to facilitate developers' understanding of what would/not be acceptable for end-users. Importantly, the approach considers context at higher macro system levels. This could help develop technologies that operate in a flexible way within the variety of organisational and cultural structures that reside within health care. Considering these contextual factors may help ensure technologies are FFP.

Limitations

The presented paper reviews 19 technologies identified via a structured literature review. The authors acknowledge there may be alternative technologies currently in use that may have scored differently on the FFP matrix. Due to the suggested limitations surrounding technological capture of Moments 2 and 3 it is unlikely such systems would

score a full FFP, i.e. be able to monitor, measure and provide feedback at all WHO 5 Moments. However the authors accept that this cannot be definitively ruled out by this review.

Conclusion

Currently the WHO are in the process of consolidating a systematic review in the area of electronic surveillance (WHO, 2013), in collaboration with renewed focus on hand hygiene monitoring and feedback for the annual Save Lives: Clean Your Hands day held on May 5 2013. Preliminary results support the view of this paper: that automated monitoring systems appear to have potential. However the authors believe that understanding these technologies and appraising them at a systems level may help further develop this area of monitoring. With further work, Human Factors will play a role in facilitating this.

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References

- Anon. (2011) System given gentle nudge on handwashing. *Health Facilities Management* **24**(2): 6.
- Anon. (2012) Product preview. *Supply House Times* **55**(7): 12–14.
- Armellino D, Hussain E, Schilling ME, Senicola W, Eichorn A, Dlugacz Y, Farber BF. (2012) Using high-technology to enforce low-technology safety measures: the use of third-party remote video auditing and real-time feedback in healthcare. *Clinical Infectious Diseases* **54**(1): 1–7.
- Bauer TM, Ofner E, Just HM, Just H, Daschner FD. (1990) An epidemiological study assessing the relative importance of airborne and direct contact transmission of microorganisms in a medical intensive care unit. *Journal of Hospital Infection* **15**(4): 301–9.
- Bhalla A, Pultz NJ, Gries DM, Ray AJ, Eckstein EC, Aron DC, Donskey CJ. (2004) Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalized patients. *Infection Control and Hospital Epidemiology* **25**(2): 164–7.
- Boscart VM, Gorski S, Holliday PJ, Hufton G, Levchenko AI, Marquez-Chin C, McGilton K, Momen K, Tsang M, Fernie GR. (2009) Advanced technologies to curb healthcare-associated infections. *Healthcare Papers* **9**(3): 51–5.
- Boyce JM. (2011) Measuring healthcare worker hand hygiene activity: current practices and emerging technologies. *Infection Control and Hospital Epidemiology* **32**(10): 1016–28.
- Cantrell S. (2012) Healthcare facilities strive to hand infections defeat. *Healthcare Purchasing News* **36**(10): 22–30.
- Carayon P, Gurses AP. (2005) A human factors engineering conceptual framework of nursing workload and patient safety in intensive care units. *Intensive and Critical Care Nursing* **21**: 284–301.
- Catchpole K, Mishra A, Handa A, McCulloch P. (2008) teamwork and error in the operating room: analysis of skills and roles. *Annals of Surgery* **247**(4): 699–706.
- Centrak – information sourced from <http://www.centrak.com/Solution-sHHCMonitoring.aspx> (Accessed 16 January 2013).
- Cheng VCC, Tai JWM, Ho SKY, Chan JFW, Hung KN, Ho PL, Yuen KY. (2011) Introduction of an electronic monitoring system for monitoring compliance with Moments 1 and 4 of the WHO 'My 5 Moments for Hand Hygiene' methodology. *BMC Infectious Diseases* **11**: 151.
- Czyzewski A. (2011) Infrared hygiene monitor put on trial. *The Engineer* **296**(7827): 10.
- Dawson C. (2013) To "Urgh" is Human... Exploring Inherent and Elective Hand Hygiene Triggers: A pilot study in the NHS. *Journal of Infection Prevention* **14** (1) Suppl: S3–S47 Abstract 2511.
- Dawson CH. (2014) Healthcare professional views on the potential for hand hygiene technologies – findings from an NHS acute setting case study.
- Do EY-L. (2009) Technological interventions for hand hygiene adherence: research and intervention for smart patient room. In: Tidafi T, Dorta T (eds) *Joining languages, cultures and visions: CAAD Futures 2009*, PUM: 303–13. Available at: http://cumincad.scix.net/cgi-bin/works/Show?cf2009_303. (Accessed 13 November 2011).
- Eckmanns T, Bessert J, Behnke M, Gastmeier P, Ruden H. (2006) Compliance with antiseptic hand rub use in intensive care units: the Hawthorne effect. *Infection Control and Hospital Epidemiology* **27**(9): 931–4.
- Edmond MB, Goodell A, Zuelzerd W, Sanogob K, Elama K, Bearmana G. (2010) Successful use of alcohol sensor technology to monitor and report hand hygiene compliance. *Journal of Hospital Infection* **76**(4): 364–5.
- El Shafie SS, Alishaq M, Leni Garcia M. (2003) Investigation of an outbreak of multidrug-resistant *Acinetobacter baumannii* in trauma intensive care unit. *Journal of Hospital Infection* **56**(2): 101–5.
- Ellingson K, Polgreen PM, Schneider A, Shinkunas L, Kaldjian LC, Wright D, Thomas GW, Segre AM, Herman T, McDonald LC, Sinkowitz-Cochran R. (2011) Healthcare personnel perceptions of hand hygiene monitoring technology. *Infection Control and Hospital Epidemiology* **32**: 1091–6.
- Ferenc J. (2012) Handy solutions. Hygiene compliance monitoring goes high-tech. *Health Facilities Management* **25**(4): 32–6.
- Ghosh A, Ameling S, Zhou J, Lacey G, Creamer E, Dolan A, Sherlock O, Humphreys H. (2012) Pilot evaluation of a ward-based automated hand hygiene training system. *Infection Control* **41**(4): 368–70.
- Gould DJ, Chudleigh J, Drey NS, Moralejo D. (2007) Measuring hand-washing performance in health service audits and research studies. *Journal of Hospital Infection* **66**(2): 109–15.

- Haas JP, Larson EL. (2007) Measurement of compliance with hand hygiene. *Journal of Hospital Infection* **66**: 6–14.
- Health Protection Scotland (HPS) (2009) National Hand Hygiene NHS Campaign Compliance with Hand Hygiene - Audit Report Health Protection Scotland. Glasgow.
- Hlady CS, Severson MA, Segre AM, Polgreen PM. (2010) A mobile handheld computing application for recording hand hygiene observations. *Infection Control and Hospital Epidemiology* **31**(9): 975–7.
- Hyginex – information sourced from <http://www.hyginex.com/?cp=585>. (Accessed 16 January 2013).
- Jeppsson J. (2011) Emerging technologies. *Industrial Engineer* **43**(2): 58–9.
- Kohli E, Ptak J, Smith R, Taylor E, Talbot EA, Kirkland KB. (2009) Variability in the Hawthorne effect with regard to hand hygiene performance in high- and low-performing inpatient care units. *Infection Control and Hospital Epidemiology* **30**(3): 222–5.
- Lin L, Vicente KJ, Doyle DJ. (2001) Patient safety, potential adverse drug events, and medical device design: a human factors engineering approach. *Journal of Biomedical Informatics* **34**: 274–84.
- Lorenzi N. (2011) Tracking changes. *Health Facilities Management* **24**(8): 36.
- Otter JA, Havill NL, Adams NMT, Boyce JM. (2006) Extensive environmental contamination associated with patients with loose stools and methicillin-resistant *Staphylococcus aureus* colonization of the gastrointestinal tract. In: 16th Annual Scientific Meeting of the Society for Healthcare Epidemiology of America, Chicago, IL, 2006; abstract 159.
- Pessoa-Silva CL, Hugonnet S, Pfister R, Touveneau S, Dharan S, Posfay-Barbe K, Pittet D. (2007) Reduction of health care associated infection risk in neonates by successful hand hygiene promotion. *Pediatrics* **120**: 382–90.
- Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V, Touveneau S, Perneger TV. (2000) Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *Lancet* **356**: 1307–12.
- Polgreen PM, Hlady CS, Severson MA, Segre AM, Herman T. (2010) Method for automated monitoring of hand hygiene adherence without radio-frequency identification. *Infection Control and Hospital Epidemiology* **31**(12): 1294–7.
- Rouse WB. (2010) *The Economics of Human System Integration*. Hoboken, NJ: J Wiley.
- Sahud AG, Bhanot N, Narasimhan S, Malka ES. (2012) Feasibility and effectiveness of an electronic hand hygiene feedback device targeted to improve rates of hand hygiene. *Journal of Hospital Infection* **82**: 271–3.
- Sax H, Allegranzi B, Uçkay I, Larson E, Boyce J, Pittet D. (2007) 'My five moments for hand hygiene': a user-centred design approach to understand, train, monitor and report hand hygiene. *Journal of Hospital Infection* **67**: 9–21.
- Sax H, Stewardson A, Allegranzi B, Boyce JM, Clack L, Larson EL, Pittet D. (2012) Beyond reasonable doubt: evidence for 'My 5 moments for hand hygiene'. *British Editorial Society of Bone and Joint Surgery*. Available at: www.bjj.boneandjoint.org.uk/content/94-B/4/441/reply (accessed 6 August 2013).
- Sealed Air – information sourced from https://www.visionenabledtraining.com/how_it_works.php (Accessed 16 January 2013).
- Surewash – information sourced from www.surewash.com/audit/ (Accessed 16 January 2013).
- Tenorio AR, Badri SM, Sahgal NB, Hota B, Matushek M, Hayden MK, Trenholme GM, Weinstein RA. (2001) Effectiveness of gloves in the prevention of hand carriage of vancomycin-resistant enterococcus species by health care workers after patient care. *Clinical Infectious Diseases* **32**(5): 826–9.
- van de Mortel T, Murgu M. (2006) An examination of covert observation and solution audit as tools to measure the success of hand hygiene interventions. *American Journal of Infection Control* **34**(3): 95–9.
- Vicente K. (2006) *The Human Factor: Revolutionizing the Way People Live with Technology*. Abingdon, Oxon, UK: Routledge.
- Wilson JR. (2000) Fundamentals of ergonomics in theory and practice. *Applied Ergonomics* **31**(6): 557–67.
- Wilson JR. (2014) Fundamentals of systems ergonomics/human factors. *Applied Ergonomics* **45**(1): 5–13.
- World Health Organization. (2009) *WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge Clean Care is Safer Care*. Geneva: WHO Press.
- World Health Organization. (2013) Hand hygiene monitoring and feedback. Available at: <http://www.who.int/gpsc/5may/automated-hand-hygiene-monitoring.pdf> (accessed 23 January 2014).

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