

Examination of the quality of hand disinfection using electronic equipment

Doctoral thesis
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Introduction

The hands of hospital staff become contaminated involuntarily with pathogenic microbes during patient care, introducing the risk of nosocomial infections. Hand hygiene with alcohol-based hand rub is considered to be the most efficient preventative tool, radically reducing residual flora on the skin.

There are several hand rubbing methods that have spread out all over the world. The generally known method for hand rubbing is the “WHO six-step protocol” covering the surface of the hand with disinfectant in six steps. There is also another method for hand rubbing called “three-step protocol” where the protocol does not contain a precise description for hand rubbing. We can also find other protocols as well, for example „self-responsible protocol”, where the healthcare workers’ decision is the method they choose for hand rubbing. “WHO six-step protocol” is supplemented with a new, 7th step, containing wrist treatment.

Increasing the compliance rate is not enough to combat hospital-acquired infections (HAI), as it does not reflect the adequacy of hand hygiene technique. In addition to performing hand hygiene at appropriate frequency, the effectiveness of hand hygiene technique is of key importance. Nowadays there appeared such electronic devices that manage compliance, monitoring and giving feedback, too.

Objectives

1. The validation of the fluorescein based computerized technology, providing a proof that it shows the location of the disinfected areas in UV box.
2. Examining the effect of the electronic device in improving the quality of education practiced in surgical hand disinfection.
3. The investigation of the effectiveness of direct feedback that helps to change the incorrectly ingrained habits and gestures into the correct hand hygiene techniques.

Methods

Fluorescein test

Areas treated properly with the UV solution show brighter under UV light, while missed areas remain darker. Through digital imaging we have the opportunity to visualize the outcome of hand rubbing performance and provide feedback and explanation about missed areas and mistakes in the HH technique.

Hand-in-Scan device

The Hand-in-Scan allows immediate evaluation of hand sanitization with a special UV-marked alcoholic hand rub solution. After having hands rubbed with hand rub solution, the surface of hands is screened under UV light. Hand-in-Scan uses intelligent and automatic image

processing procedures, which can reliably and objectively separate the properly and improperly rubbed areas on the hands' surface (Fig. 1).



Figure 1: Prototype of Hand-in-Scan device

Classification by the missed areas during hand rubbing

To get more accurate feedback during our study we divided the hand surface into 20 regions (10 of the palms and 10 of the dorsum).

The missing areas were determined by the digital images and the results were organized into excel tables.

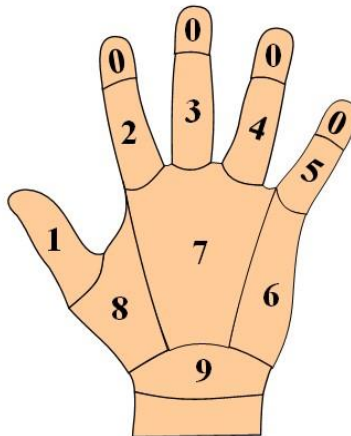


Figure 2: Regional division of the surface of the hand.

Microbiology validation

At the first step we compared the result of the fluorescein test with the dispersion of the disinfectant. The coverage of the disinfectant indicated by the UV-box was tested against microbiological cultivation results by comparing digital images of both. We used fluorescein based computerized technology to assist this work. We compared the correlation between microbiology results and software-based evaluation of Hand-in-Scan device. For the experiment, artificial hands were fabricated from plastic and covered with cow skin. This hand was soaked into high concentration (0.5 McF) *Staphylococcus epidermidis* suspension. In each experiment one selected hand region was treated with alcohol-based hand-rub, containing fluorescent dye. Digital image of the hand was recorded and the artificial hand was stamped into a blood agar plate. The plate was incubated at 37°C for 48 hours. The two resulting images were compared using image processing software, the one embedded into the Hand-in-Scan device. Both recordings were made of the same artificial hands so the entire area of interest was the same on both (24.2 cm²). After registering hand boundaries (edges) to each other, we were able to map each pixel of one image to the corresponding pixel of the other image. This way we could actually determine, to what extent the bright regions on UV images, and pathogen free areas match each other. We evaluated the number of true positives, true negatives, and false positives, and subsequently established the specificity and sensitivity of the fluorescein probe.

The assessment of surgical hand washing

The Basic Surgical Techniques subject offered for third-year medical students at Semmelweis University (Budapest), is a regular class, consisting of two hours lecture and three hours practice every second week, teaching the basics of interventional medicine. Surgical hand washing (SHW) is included in the topic of the first practice hours. Since 2011, the practical education has included the UV-box-based assessment of students' HH quality. Following the regular steps of SHW, after the soap based hand washing, students are asked to rub their hands four times using an ABHR solution. As a last step, students used UV-dye enabled ABHR for the study. After that, the Hand-in-Scan device was employed to monitor the hand coverage and to give immediate visual feedback concerning the missed areas. The quality of the acquired HH technique was evaluated with this computerized technology, investigating the most frequently missed areas. The statistical analysis of missed areas was based on retrospective expert evaluation of the recorded images. Missed areas were grouped according to their location on the hand. Only those students were declared passed, who did not miss any spots on either side of their hands. Data collection was performed during a four-year period at Semmelweis University (Budapest, Hungary) and University of Medicine and Pharmacy of Tîrgu Mureş (Romania). 1,344 medical students participated in the study: 518 males and 826 females. Participants were not differentiated by age, as they all were third-year medical students. Each participant received a unique identifier when the personal information was recorded (gender and dominant hand),

which was also used to connect each recorded image with the corresponding person in an anonymous manner.

Repetitive hand hygiene technique assessment

The repetitive study covered nine wards of three hospitals in Hungary, and was performed between October 2013 and August 2014. Participants were asked to rub their hands with an ultraviolet (UV)-labelled disinfectant solution. Digital images of both sides of the hands were taken under UV-A light. Recording the HR events also allowed the infection control team to analyze the images retrospectively.

Hospitals joined the study on a voluntary basis. The Hand-in-Scan device was used in each ward for two to four weeks for data collection. HCWs were included anonymously in the study on a voluntary basis. Most participants were nurses and allied health workers, with a small number of physicians. HCWs were asked to complete a survey (providing information on sex, age range, position, years in the institution and dominant hand), and were given numbered RFID cards, where only the number connected each participant to their survey.

Data collection was performed in each ward according to the same protocol. The chief nurse turned on the data collection device. Participants could appear any time during their shift, check in using their RFID, and perform the assessment. The Hand-in-Scan device gave each participant instant visual feedback, indicating the areas that were missed during their HH. Most participants returned to the device every three to five days, enabling the infection control team to follow changes in their HH technique over time.

The Hand-in-Scan device stored all images together with the RFID information, and time stamped each record. Data were collected for

retrospective analysis every two to three days. Records were analyzed manually using a predefined set of criteria. At the end of the study, the management of participating institutions received a detailed report on the performance of their HCWs. We summarized the data of the 168 participants (Table 1):

Table 1: The overall participants of hand hygiene survey from October 2013 to September 2014, conducted in 9 wards.

Gender		Age			Dominant hand	
<i>M</i>	<i>F</i>	<25	26-45	46+	<i>R</i>	<i>L</i>
11	157	12	107	49	158	10

Statistical analysis

Every observation (i.e. number of mistakes for a given HR event for a given individual) is assumed to follow a Poisson distribution. Generalized Estimating Equation (GEE) modelling was performed to model within-subject correlation. The only covariate was the number of measurements for the subject. In total, 168 HCWs took part in the study. However, only 136 participants provided at least two measurements. The total number of observations considered was 631. HR events were categorized into three groups, defined as: (a) no mistakes; (b) one to three mistakes; and (c) at least four mistakes. Statistical analysis was performed using R version 2.15.0. The GEE model estimation was performed using R library *geepack*. Effects were considered significant at $P < 0.05$. Confidence intervals were computed using the Wilson method.

Results

Microbiology validation

We had a total number of 25 measurements.

Table 2: Last two columns indicate the sensitivity and specificity of the fluorescein probe

Shape	TP	FN	FP	TN	Sensitivity (%)	Specificity (%)
1	22197	2385	835	174582	90.3	99.5
2	34962	2361	990	161687	93.7	99.4
3	34823	3432	3863	157881	91.0	97.6
4	41433	2473	1905	154189	94.4	98.8
5	41179	1838	7026	149958	95.7	95.5
6	38793	1844	3941	155422	95.5	97.5
7	36456	1312	3925	158307	96.5	97.6
8	45490	2547	7071	144892	94.7	95.4
9	40680	2019	7613	149688	95.3	95.2
C	29584	1844	1898	166674	94.1	98.9
D	25799	555	1755	171890	97.9	99.0
H	44262	1404	11358	142976	96.9	92.6
L	37251	5693	379	156677	86.7	99.8
T	22105	441	4034	173419	98.0	97.7
V	31820	3205	510	164465	90.9	99.7
Y	46148	1377	4663	147813	97.1	96.9
Z	39893	3875	2524	153707	91.2	98.4
Cross (+)	43542	2085	4602	149771	95.4	97.0

Triangle	37209	681	3748	158362	98.2	97.7
Circle	40867	1122	1615	156396	97.3	99.0
Trapezoid	45556	714	1394	152337	98.5	99.1
Diamond	40080	966	916	158038	97.7	99.4
Smiley	37646	1785	1111	159457	95.5	99.3
Heart	40012	1126	635	158227	97.3	99.6
Rectangle	33640	1185	633	164542	96.6	99.6
Overall	931429	48269	78945	3941357	95.1	98.0
Average ± Standard deviation					95.1±3.0	98.0±1.8
Median					95.5	98.8
(CI 95%)					(94.4–96.6)	(97.9–99.6)

The average values for sensitivity and specificity were obtained 95.1% and 98%, respectively. The minimum values for sensitivity and specificity were obtained 86.7% and 95.2% respectively, while the maximum values were both above 99%.

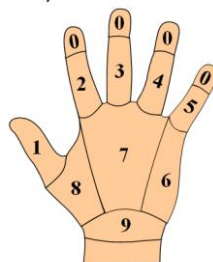
The assessment of surgical hand washing

On the palmar side of hands, there was a negligible incidence of missed areas: a total number of nine participants failed to achieve full coverage, and only four of them on both palms. As rubbing the palms is the first step of hand rubbing, it is performed when there is still an abundant amount of ABHR on the hand surface, allowing for satisfactory coverage of the palms. On the dorsal side of hands, a total number of 2,306 missed spots were found aggregated for the participants, out of which 1,277 were on the right hand, and 1,029 on the left hand. Hand rubbing performances were classified into two

groups: those who passed and those who failed the assessment, where all those failed the assessment who had at least one missed spot (Table 3).

Table 3: The medical students' survey result (2011-2014) were based on the missed areas after hand rubbing.

Region	Number of missed areas	
	left hand	right hand
0	490 (47.6%)	537 (42.0%)
1	244 (23.7%)	305 (23.8%)
2	36 (3.5%)	60 (4.7%)
3	34 (3.3%)	51 (3.9%)
4	31 (3.0%)	50 (3.9%)
5	29 (2.8%)	37 (2.8%)
6	50 (4.8%)	62 (4.8%)
7	21 (2.0%)	31 (2.4%)
8	70 (6.8%)	112 (8.7%)
9	24 (2.3%)	32 (2.5%)
Total	1,029	1,277



Out of 1,344 participants, 513 (38.2%, CI 95%: 36–41%) failed to perform acceptable hand rubbing as given in the above condition. In the case of female participants, the failure rate was 35.47% (CI 95%: 32–38%), while for males it was 43.4% (CI 95%: 39–48%), $p = 0.002$. Regarding the role of the dominant hand, close to 90% of the participating students were right handed, a ratio corresponding to the general statistics. Missed areas were found on 35.3% (CI 95%: 33–38%) of the dominant hands and 29.0% (CI 95%: 27–31%) of the non-dominant hands, $p < 0.001$. Almost the same figures were obtained when the coverage on the right and left hands was compared. Coverage was insufficient on 34.8% (CI 95%: 32–37%) of the right hands and 29.5% (CI 95%: 27–32%) of the left hands, $p < 0.004$. Results show that the dominant hand gets worse coverage than the non-dominant

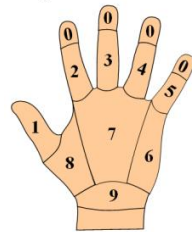
one, which can be explained by the fact that the dominant hand is used to rub the non-dominant hand and vice versa, and people can perform activities more precisely with their dominant hand.

Repetitive hand hygiene technique assessment

At each hand rubbing (HR) event, missed sites were identified on the surface of both hands. The absolute number of mistakes was compiled for each measurement of each participant at each HR event. On the palmar side of hands, there was a negligible incidence of missed areas: a total number of missed areas was only 19. On the dorsal side of hands, a total number of 680 missed areas were found aggregated for the participants, out of which 359 were on the right hand, and 321 on the left hand (Table 4).

Table 4: The hand hygiene survey of 9 classes took place between October 2013 and September 2014, involved 168 healthcare participants who performed 730 hand rubbing events.

Region	Number of missed areas			
	Left dorsum	Right dorsum	Left palm	Right palm
0	119 (37%)	122 (34%)	0	0
1	79 (25%)	86 (24%)	8	10
2	14 (4%)	18 (5%)	0	0
3	15 (5%)	14 (4%)	0	0
4	14 (4%)	12 (3%)	0	0
5	11 (3%)	11 (3%)	0	0
6	23 (7%)	36 (10%)	0	0
7	13 (4%)	18 (5%)	0	0
8	22 (7%)	32 (9%)	0	0
9	11 (3%)	10 (3%)	1	0
Sum	321	359	9	10
Total	680		19	



The volunteers were asked to routinely assess their hand hygiene technique with Hand-in-Scan, until they learned to achieve and maintain complete coverage. The retrospective analysis of 730 observations revealed that the number of people making mistakes at all was reduced from 42% to 13% (Figure 2).

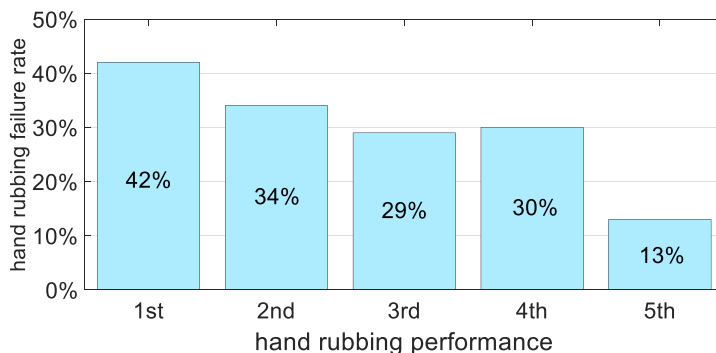


Figure 2: *The hand hygiene survey of 9 classes took place between October 2013 and September 2014, involved 168 healthcare participants who performed 730 hand rubbing events.*

Statistical analysis

Table 5: *Significance tests on the selected hypothesis regarding hand rub (HR) quality evolution.*

Observation	Number of observations	Inadequate performances	Number of mistakes	Rate of inadequate performances (95% CI)
1	136	67	245	49.3% (41.0–57.6)
2	136	46	150	33.8% (26.4–42.1)
3	100	29	122	29.0% (21.0–38.5)
4	81	24	54	29.6% (20.8–40.3)
5	60	8	28	13.3% (6.9–24.2)
6–10	118	21	54	17.8% (11.9–25.7)
1	136	67	245	49.3% (41.0–57.6)
2–4	317	99	326	31.2% (26.4–36.5)
5–10	178	29	82	16.3% (11.6–22.4)

Tables 5 show the statistics for inappropriate HH technique and missed areas. The rate of unsatisfactory HH technique dropped in two steps, from almost 50% to approximately 16%. The first relevant step was achieved immediately after the first HR event (49.3% missed at first measurement, 31.2% at following measurements, $P < 0.001$), while the second step was achieved after the fourth HR event, reducing the rate of inappropriate HH technique from 31.2% to 16.3% ($P < 0.001$).

Table 6: Primary statistics of hand hygiene observations according to their temporal order.

Statement	P-value
Second to fourth HR event (99/317) has better coverage than first HR event (67/136)	<0.001
Fifth to tenth HR event (29/178) has better coverage than second to fourth HR event (99/317)	<0.001
Transition from one to three mistakes to no mistakes (77/115) is more frequent than transition from no mistakes to one to three mistakes (51/325)	<10 ⁻¹⁵
Transition from four or more mistakes to no mistakes (29/55) is more frequent than transition from no mistakes to four or more mistakes (13/325)	<10 ⁻¹⁵
Transition from four or more mistakes to one to three mistakes (13/55) is more frequent than transition from one to three mistakes to four or more mistakes (11/115)	0.025
Transition from one or more mistakes to no mistakes (106/170) is more frequent than transition from no mistakes to one or more mistakes (51/325)	<10 ⁻¹⁵

The latter two groups were combined into the group with at least one mistake. Each pair of consecutive observations represents a ‘group-to-group’ transition. The statistics of such transitions are shown in Table 6 indicating the likelihood of each transition. Recorded data suggest

that for any pair of groups, the two-way transitions between them are significantly more frequent in the direction of better performance; in other words, HH technique evolves in time towards completeness.

Conclusions

1. *The result of fluorescein test corresponds to the dispersion of the disinfectant on the hand surface.*

The outcome of the fluorescein test was investigated via microbiological sampling, which showed 98% specificity, indicating the high accuracy of the fluorescein test.

2. *Direct visualization of mistakes via the Hand-in-Scan device enables correcting wrong practices, and eliminates erroneous habits. Using device can help us to be aware of the missed areas that can help us to practice the right hand hygiene methods.*

The visualization of hand rubbing quality indicated inadequate coverage at 38% of the students, who were thus confronted with their mistakenly learned hand rubbing movements.

3. *Repetitive practice with immediate objective feedback improves the hand hygiene technique.*

Through self-assessment, the users of the electronic equipment can practice the hand rubbing movements without the supervision of the expert. At first use 49% of the healthcare workers performed inadequate hand rubbing, which reduced to 13% at the fifth use.

Publications

Publications related to the PhD dissertation in scientific journals:

1. L. Szilágyi, T. Haidegger, *Á. Lehotsky*, M. Nagy, E. A. Csonka, X. Sun, K. L. Ooi & D. Fisher, A large-scale assessment of hand hygiene quality and the effectiveness of the WHO 6-steps, *BMC Infectious Diseases* vol. 13, art. 249, 2013. doi: 10.1186/1471-2334-13-249.
2. *Á. Lehotsky*, L. Szilágyi, T. Ferenci, L. Kovács, R. Pethes, Gy. Wéber, T. Haidegger, The quantitative impact of direct, personal feedback on hand hygiene technique. *Journal of Hospital Infection*.vol. 91. issue 1, pp. 81-84, 2015. doi: 10.1016/j.jhin.2015.05.010.
3. *Á. Lehotsky*, L. Szilágyi, Gy. Wéber, T. Haidegger, Education of hand rubbing technique to prospective medical staff employing UV-based digital imaging technology. *Acta Microbiologica et Immunologica Hungarica*, 63 (2), pp. 1–12 (2016), doi: 10.1556/030.63.2016.2.7