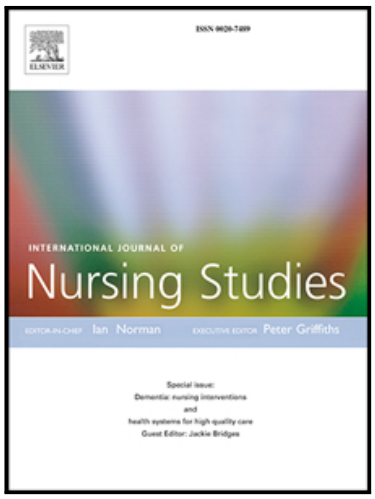

The association between shift patterns and the quality of hand antisepsis in a neonatal intensive care unit: an observational study

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Title: The association between shift patterns and the quality of hand antisepsis in a neonatal intensive care unit: an observational study

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Abstract:

Background: Healthcare-associated infections represent a major burden in neonatal intensive care units. Hand antisepsis is the most important tool for prevention, however, compliance among healthcare workers remains low.

Objectives: To prospectively evaluate the influence of different work shifts (extended working hours, night shifts) on the quality of healthcare workers' hand antisepsis.

Design: Observational study.

Settings: Two equivalent “Level III” neonatal intensive care units at the University Hospital Vienna, Austria.

Participants: Seventy healthcare workers, 46 nurses and 24 physicians.

Methods: The Semmelweis Scanner, an innovative training device assessing the quality of hand antisepsis with an ultraviolet dye labelled alcohol-based hand rub, was employed to collect data on the hand surface coverage achieved during hand antisepsis of participants. It provides visual feedback of appropriately versus inappropriately disinfected areas of the hand and can also be used for the objective quantification of hand surface coverage with the hand rub. Measurements were performed before and after 12.5 hour (h) day and night shifts (nurses), as well as before and after regular 8h day shifts and extended 25h shifts (physicians). To avoid any bias caused by residual ultraviolet marker, scans had to be separated by 24 hours periods. Primary outcome was the hand surface coverage with the hand rub: Hand scans were categorized as “passed” if an appropriate quality of hand hygiene, defined as a minimum 97% coverage of hand surface, was achieved. A generalized mixed model was used to analyse the data accounting for repeated measurements.

Results: Seventy healthcare workers performed a total of 485 scans. Sixteen scans had to be excluded, resulting in 466 scans for further analyses. A difference in the predicted probability of achieving appropriate hand antisepsis was found between the beginning and end of extended shifts: In physicians, adequate hand antisepsis was remarkably reduced after 25h shifts (predicted probability 99.4% vs 78.8%), whereas there was no relevant difference between the beginning and end of 8h day shifts (92.2% vs 97.3%). In nurses, a relevant difference was found between the beginning and end of 12.5h day shifts (88.6% vs 73.6%). This difference was not found for 12.5h night shifts. The most frequently missed area on the hands was the right dorsum.

Conclusion: The quality of hand antisepsis of healthcare workers in neonatal

intensive care units may be associated with long working hours.

Contribution statement:

What is already known about the subject of the paper:

- Hand hygiene is a key measure to prevent healthcare-associated infections, however, compliance rates of healthcare workers are heterogeneous and remain notoriously low.
- The quality of hand hygiene performance (i.e., the coverage achieved) is rarely assessed.
- Long working hours and disruption of the circadian rhythm may have an impact on alertness and work performance.

What this paper adds:

- Extended working hours in nurses and physicians were inversely correlated with the quality of hand antisepsis, defined as minimum 97% coverage of hand surface area with the disinfectant.
- The most frequently missed area of the hands was the right dorsum.

Keywords:

Hand hygiene; healthcare-associated infection; neonatal nursing; patient safety; quality assurance; hand antisepsis training tool; shift work schedule.

Introduction

Healthcare-associated infections represent a major challenge in neonatal intensive care units globally. Bloodstream infections are the most common healthcare-associated infections in very low birth weight infants (Giannoni et al., 2018, Legeay et al., 2015, Leistner et al., 2013). Reports on rates are depending on definitions and differ between 8.6 per 1000 patient days (in preterm born infants <1500 g birthweight) in the German Neo-KISS network (Leistner et al., 2013) and 6.3 per 1000 patient days (700 g -1200 g birthweight) in the U.K. (Leighton et al., 2012). Affected neonates have a higher risk for prolonged hospital stay, poor neurological outcome, or even death (Legeay et al., 2015, Schlapbach et al., 2011, Schwab et al., 2015, Stoll et al., 2002). Hand antisepsis has been identified undisputedly as a key measure to prevent healthcare-associated infections (Pittet et al., 2009, WHO, 2009). Achieving best hand hygiene compliance in healthcare workers therefore is essential to improve patient safety.

The World Health Organization (WHO) recommends hand hygiene by using alcohol-based hand rubs before, during and after prolonged and intense contact with any patient (WHO, 2009). Notably, compliance among healthcare workers remains low. A recent study among six European intensive care units showed heterogeneous hand hygiene with compliance rates ranging from only 3% to 100% (Musu et al., 2017), and with overall low levels of adherence to best hand hygiene practices. For the past decades, a so-called “multimodal approach” has been advocated by the WHO to increase compliance towards hand hygiene (Allegranzi et al., 2013, Pittet et al., 2000). For instance, an educational program in a neonatal intensive care unit was able to increase the overall hand hygiene compliance before patient contact from 65% to 88%, and resulted in a reduction in healthcare-associated bloodstream infections in very low birth weight infants (Helder et al., 2010). However, such quality

improvements do not often show persistence as passive educational methods alone are mostly insufficient as a change strategy (di Martino et al., 2011, Soong and Shojania, 2020, von Lengerke et al., 2017). Therefore, ongoing audits and awareness campaigns together with regular feedback to healthcare workers seem to be beneficial to maintain high compliance rates (Ivers et al., 2012).

In addition, simply performing hand antisepsis does not imply that the procedure is done efficiently. While traditionally, most research has focused on improving hand hygiene compliance regarding the frequency of application, little attention has been paid to the quality, meaning the completeness of hand coverage with the disinfectant. Coverage of hand rub was earlier shown to correlate with quality of hand hygiene through microbiological analyses (Sari et al., 2019). A study conducted by Szilagyi et al. including 5,200 clinical staff members reported a failure rate of 28% in achieving satisfactory hand hygiene quality immediately after training the “WHO five moments” (Szilagyi et al., 2013). Another study assessing healthcare workers from 26 Hungarian hospitals found that 33% failed to apply the hand rub correctly (Lehotsky et al., 2017). Hence, even with education and training, compliance to hand hygiene standards often remains poor, therefore, understanding the mechanisms for non-compliance is key.

One factor not yet thoroughly investigated in the context of hand hygiene is occupational stress, such as prolonged working hours or night shifts. Long working hours can induce a lack of concentration and fatigue, which in turn has been shown to be related with worse patient outcomes (Gander et al., 2019, Maltese et al., 2016, Sturm et al., 2019, WHO, April 2009). Several studies have shown the influence of extended work shifts on serious medical errors and occupational injury (Fletcher et al., 2011, Landrigan et al., 2004, Lo et al., 2016, Stimpfel et al., 2015). Notably, a

prospective, randomized study conducted by Landrigan et al. demonstrated that physicians working in “traditional” schedules with extended 24h shifts made 35.9% more severe medical errors as well as 5.6 times as many severe diagnostic errors compared to an intervention schedule with reduced working hours (Landrigan et al., 2004). In another very recent study on nurses´ work patterns and its association with fatigue and fatigue-related outcomes, 30.8% of participating nurses reported fatigue-related errors during the last 6 month (Gander et al., 2019). These data are in line with an investigation on the impact of intensive care unit night shifts on the cognitive performance of physicians, showing significantly worsened working memory capacity, speed of processing information, perceptual reasoning, and cognitive flexibility after night shifts (Maltese et al., 2016). However, none of these studies evaluated the influence of extended work shifts and night shifts on the quality of hand hygiene.

We hypothesized in this study that prolonged working hours and night shifts may have an impact on hand hygiene quality, an important component of patient safety, in a neonatal intensive care unit. According to the act on working hours in Austria, 8h day shifts and extended 25h day and night shifts for physicians, as well as 12.5h day and night shifts for nurses are standard at the University Hospital Vienna. The aim of this clinical observational study was to prospectively evaluate if different work shifts and duration of working hours have an impact on hand antisepsis quality of healthcare workers in a neonatal intensive care unit, as measured and quantified by the Semmelweis Scanner.

Methods

Study design

In order to examine the influence of different work shifts on hand antisepsis performance of healthcare workers, we conducted an observational study, and analysed the quantified hand antisepsis quality at the beginning and end of shifts. The study was performed in two equivalent “level III” neonatal intensive care units at the University Hospital in Vienna, Austria, between November 2017 and April 2018. The “Semmelweis Scanner” (HandInScan Zrt., Debrecen, Hungary) was used to assess the quality of hand antisepsis.

Semmelweis Scanner

The Semmelweis Scanner is a recently developed, CE marked training tool educating users about the quality of the hand rubbing technique by providing visual feedback of appropriately versus inappropriately disinfected areas of the hand. The device generates digital-image-based evaluation of hand surface coverage with an ultraviolet dye labelled alcohol-based hand rub and can also be used for the objective quantification of hand coverage with the disinfectant, saving the results in an online reporting database for posterior evaluation.

The Semmelweis Scanner was employed to monitor hand antisepsis quality as described and validated previously by Haidegger et al. and Lehotsky et al. (Haidegger et al., 2011, Lehotsky et al., 2017). At the beginning and at the end of shifts, digital images of both sides of the hands were taken by the device after regular hand rubbing with an ultraviolet dye labelled alcohol-based training rub (Optik, Schülke & Mayr GmbH, Norderstedt, Germany). Artificial intelligence-based image processing was used to identify any missed areas on the hands (Haidegger et al.,

2011, Lehotsky et al., 2015). For each measurement of each participant, the percentage of hand surface coverage was determined. Based on established educational metrics (Nagy et al., 2017), a minimum coverage of 97% of each hand surface (palm and dorsum of left and right hand, each) was considered acceptable and categorized as “passed”. If the coverage of any of the four surfaces (palm and dorsum of left and right hand) was below 97%, the whole measurement was categorized as “failed”.

Moreover, to analyse most frequently missed areas of hand antisepsis, each hand surface was divided into 10 regions (0-9) as shown in Figure 1, and an error in coverage in any of these particular regions was counted as a miss, which were later computed for all measurements. Repeated measurements within 24h were not allowed and excluded from the study to avoid any possible bias caused by residual ultraviolet marker.

Data collection

Registered nurses and physicians working in one of the two neonatal intensive care units were eligible for participation and were included on a voluntary basis. They were asked to scan their hands after hand antisepsis at the beginning and end of 12.5h day and night shifts (nurses) as well as at the beginning and end of regular 8h day shifts and extended 25h shifts (physicians). Two scans pre and post each shift were targeted, resulting in 8 scans per healthcare worker. To avoid any bias caused by residual ultraviolet marker, scans had to be separated by 24 hours at least, consequently, pre and post shift scans had to be done on different days. Resting times after shifts were respected according to the act on working hours in Austria: 16h or 23h resting time provided after 8h shifts and 25h shifts, respectively, for physicians, and a minimum of 11 hours between shifts for nurses.

Due to regular obligatory hand hygiene education and trainings by the team of the hospital hygiene department, all participants were trained and familiar with the correct hand rubbing technique and did not require any additional training. The results of the measurements were blinded for all participants to prevent bias during subsequent scans. Images of hand-rubbing events were recorded using the Semmelweis Scanner. In order to maintain personal data protection, all participants received a Radiofrequency Identification (RFID) card with a random number allowing to link the scan results with the anonymized participant's demographic information. Personal data of participating healthcare workers regarding sex, age, dominant hand, and occupation group were collected via a paper questionnaire.

Outcome measures

The primary outcome was the hand surface coverage with the disinfectant, observed before and after shifts. Hand scans were categorized as "passed" if an appropriate quality of hand hygiene, defined as minimum 97% coverage of hand surface, was achieved.

Statistical Analysis

Hand antisepsis quality was computed as a percentage of the measured coverage with ultraviolet dye labelled alcohol-based training hand rub. 8 scans per healthcare worker were targeted for each data series, but not all participants managed to complete that. To model the impact of the type of shift, and the possible effect of being pre or post shift, a mixed model was used. The mixed model accounts for the intra-individual correlation of the repeated measurements, i.e., that the same subject was measured several times, and also automatically adjusts if the number of measurements differs between subjects (Pinheiro and Bates, 2000). As outcomes

were binary (pass/fail), a generalised mixed model was used, with binominal response distribution and logit as the link function (Faraway, 2016). Modelling was done separately for physicians and nurses. Explanatory variables were the type of the shift when the measurement was performed (i.e., 8h day shifts or 25h shifts for physicians, 12.5h day or night shifts for nurses) as a binary indicator and a binary indicator whether the particular measurement was made before or after the shift. The interaction of these indicators was also included, allowing all four possible combinations to take separate values. Results are presented at the response scale, i.e., as predicted probability of passing the test for the possible combinations with 95% confidence intervals. 95% confidence intervals were calculated using parametric bootstrap with the percentile approach (Davison and Hinkley, 1997). Calculations were carried out under R statistical environment version 3.6.3 (R Core Team (2019) using package lme4, version 1.1-21 (Bates et al., 2015).

The inter-person comparison was performed by creating three categories on the basis of the possible outcome of two measurements (Pass-Pass, Pass-Fail and Fail-Fail). The proportion of participants in each of the three possible categories was expressed as percentage, together with the 95% confidence interval (obtained with Clopper-Pearson exact method). With respect to the most frequently missed areas, the average occurrence of failure in each region was computed for all measurements, per occupation.

Ethics statement

The study protocol was submitted to the ethics committee of the Medical University of Vienna, which decided that an ethic committee vote was not necessary. All healthcare workers gave written informed consent prior to participation.

Results

Seventy healthcare workers, 46 nurses and 24 physicians, performed a total of 485 scans. Ten scans were excluded because the time from the previous scan was less than 24 hours and 9 scans were excluded because of duplicated measurements, leaving 466 scans for further analysis (166 scans done by physicians, 300 scans done by nurses, Table 1). The overall pass rate was 78.3% (95% CI = 74.3% - 82.0%). Thereof, 87.3% of scans done by physicians (95% CI = 81.3% - 92.0%) and 73.3% of scans done by nurses (95% CI = 68.0% - 78.3%) passed the hand antisepsis criteria of minimum 97% hand coverage.

	physicians	nurses
participants, n	24	46
male, n (%)	9 (37.5)	0 (0)
dominant hand left, n (%)	1 (4.2)	1 (2.2)
hand scans, n total (% passed)		
scans for analysis	166 (87.3)	300 (73.3)
8h day shift beginning	43 (86.1)	
8h day shift end	42 (92.9)	
25h day+night shift beginning	40 (97.5)	
25h day+night shift end	41 (73.2)	
12.5 day shift beginning		81 (80.2)
12.5 day shift end		83 (66.3)
12.5 night shift beginning		62 (74.2)
12.5 night shift end		74 (73.0)

Table 1: Demographic data and hand scans performed by physicians and nurses, grouped by occupation and shift type. Data on hand scans are given as total number, with percentage passed in parentheses.

Figure 2 plots the predicted probability of passing the minimum coverage of 97% depending on the timing of scanning before or after different shifts. Pertaining to the hand antisepsis quality among physicians, there was no relevant difference in hand hygiene performance between the beginning and end of 8h day shifts [predicted

probability 92.2% (95% CI = 81.9% - 99.5%) versus 97.3% (95% CI = 89.3% - 100%), respectively] while the predicted probability of achieving an adequate hand hygiene quality was remarkably higher at the beginning of a 25h shift compared to the end of shift [99.4% (95% CI = 95.4% - 100%) versus 78.8% (95% CI = 62.8% - 96.9%), respectively].

In the nurse group, interestingly, there was a relevant difference in the predicted probability for passing the minimum 97% coverage between the beginning and end of 12.5h day shifts [88.6% (95% CI = 77.9% - 96.0%) versus 73.6% (95% CI = 59.0% - 86.4%), respectively], while there was no difference in the predicted probability between the beginning and end of 12.5h night shifts [81.8% (95% CI = 68.4% - 93.6%) and 81.8% (95% CI = 69.5% - 91.3%), respectively] (Fig. 2).

In an inter-person comparison between scans done before or after shifts, noting that these scans were done on different days, 10.0% (95% CI = 4.8% - 16.4%) of physicians performed better at the beginning of 8h shifts, while 65.0% (95% CI = 57.8% - 71.2%) showed a similar performance and 25.0% (95% CI = 20.9% - 30.1%) a worse performance compared to the end of 8h shifts. Conversely, when comparing scans done before and after 25h shifts, 40.0% of physicians (95% CI = 32.4% - 47.7%) performed better at the beginning of shifts, 55.0% (95% CI = 46.9% - 62.4%) presented comparable scan results at the beginning and end of shifts, and 5.0% (95% CI = 2.1% - 9.2%) had worse scans at the beginning compared to the end of shifts.

Looking on the inter-person comparison of nurses, 29.3% (95% CI = 24.3% - 34.2%) of nurses performed better at the beginning of day shifts, while 56.1% (95% CI = 50.3% - 61.5%) showed a comparable and 14.6% (95% CI = 11.2% - 19.5%) a worse

performance compared to the end of day shifts. For night shifts, 18.8% (95% CI = 14.7% - 23.7%) showed better scan results at the beginning of shifts, 59.4% (95% CI = 54.0% - 64.9%) presented comparable scans at the beginning and end of shifts, and 21.9% (95% CI = 17.5% - 25.8%) performed worse at the beginning compared to the end of shifts.

Interestingly, the inter-person comparison of both occupation groups showed one person´s hand antisepsis performance at the beginning of shifts as a good predictor for the hand antisepsis quality at the end of shifts (Fig 3): when ranking alcohol-based hand rub coverage, those staff members who performed worse at the beginning of shifts mostly had a lower alcohol-based hand rub coverage at the end of shifts, and vice versa.

Overall as well as in both occupation groups, the most frequently missed area of disinfected hands was the right dorsum (Fig 4). When looking in detail on the different regions of the hands, as shown in Figure 1, both occupation groups showed a similar distribution pattern of errors in coverage. Most frequently missed areas were the dorsal side of the right thumb (region 1: 8.59% of the total number of scans done by doctors; 17.08% of scans done by nurses), fingertips (region 0: 7.36% and 17.39%, respectively) and base of the thumb (region 8: 5.52% and 11.80%, respectively) as well as on the left hand the palmar side of the fingertips (region 0: 5.52 % and 16.46%, respectively), the dorsal side of the thumb (region 1: 6.13% and 16.77%, respectively), and in scans done by nurses also the dorsal fingertips (region 0: 13.66%) (Fig 4). Detailed numbers regarding the occurrence of errors in coverage per region are given in the supplemental materials Table S1. Remarkably, when looking at the inter-person comparison, the right dorsum was the area with the highest variability of rub coverage between beginning and end of shifts.

Discussion

Healthcare-associated infections are an important cause of morbidity and mortality in neonatal intensive care units. Organisms causing infections are mostly transmitted by the hands of nurses, physicians, and other individuals taking care of neonates. Therefore, hand antisepsis is one of the most important measures of prevention (Pittet et al., 2009, Pittet et al., 2000). To the authors' best knowledge, the present study is the first evaluating the influence of extended working hours and night shifts of healthcare workers on the quality of hand antisepsis. The results from this study suggest that long working hours and extended shifts might have an impact on the quality of hand hygiene. Although all participants were aware of the ongoing measurements with the Semmelweis Scanner, the predicted probability of achieving appropriate hand antisepsis quality was remarkably reduced after prolonged working hours as 12.5h day shifts of nurses and 25h shifts of physicians. Nonetheless, a strong inter-person correlation was observed between the initial results and those at the end of shifts. Best hand antisepsis quality was found at the beginning of day shifts and at the end of 8h shifts.

Importantly, simply performing hand antisepsis does not necessarily imply that the procedure is done correctly. Paula et al. investigated the effect of hand hygiene training on the quality of hand antisepsis in terms of the proportion of wetted to un-wetted skin of hands after application of an ultraviolet dye labelled alcohol-based hand rub (Paula et al., 2018). They observed an increased percentage of wetted hand surface when comparing trained with untrained participants (Paula et al., 2018). Kampf et al. demonstrated that the use of a reduced volume of alcohol-based hand rub leads to insufficient coverage of hands, and decreased antibacterial reduction (Kampf et al., 2013). Similar results were shown by Zingg et al., indicating that in most cases of hand antisepsis an insufficient volume of alcohol-based hand rub is

used (Zingg et al., 2016). Consequently, an insufficient coverage of hands may contribute to increased healthcare-associated infection rates.

In this study, we focused on the quality of hand antisepsis, defined as the percentage of hand surface covered with an alcohol-based hand rub. To assess healthcare worker´s hand antisepsis quality, a novel hand hygiene training device was employed, providing digital images of the participants' hands taken under ultraviolet-A light after applying an ultraviolet dye labelled alcohol-based hand rub, and objectively identifying missed areas after hand antisepsis. The most frequently missed area of hand coverage was the right dorsum, which is in line with previous literature showing that the non-dominant hand is typically less dexterous in spreading the hand rub (Lehotsky et al., 2016). Therefore, continuous hand hygiene training and feedback seems to be essential also for the experienced staff.

The European Working Time Directive (2003/88/EC), as well as the Accreditation Council for Graduate Medical Education (ACGM) placed work-hour restrictions on healthcare workers with the goal to improve patient safety. Several studies demonstrated the effects of excessive duty hours or sleep deprivation of healthcare workers on serious medical errors (Fletcher et al., 2011, Hutter et al., 2006, Landrigan et al., 2004, Stimpfel et al., 2015); however, none of them evaluated the influence of extended work shifts and night shifts on the quality of hand hygiene. So far, only one study analysed the impact of time at work on compliance towards hand hygiene in a health care setting (Dai et al., 2015). It was reported that hand hygiene compliance rates decrease from the beginning to the end of a typical 12h work shift, and that the decline in compliance was magnified by increased work intensity. Conversely, longer breaks between work shifts subsequently increased compliance (Dai et al., 2015). In a recent study of our group, we could demonstrate that higher

nurse workload was associated with clinically relevant higher occurrence of blood stream infections in very low birth weight infants (Kung et al., 2019). Both prior studies support the results of our current study, demonstrating an association between long working hours and hand hygiene quality. It might seem unexpected that scans performed by nurses showed a remarkable difference between the beginning and end of 12.5h day shifts but not of night shifts. In this context, numerous studies analysing stress of nurses in intensive care units have observed that nurse workload is relevantly higher during day shifts with higher work pulse, physical activity and significantly shorter rest periods compared to night shifts, which might have an impact on concentration and compliance (Armstrong et al., 2015, Debergh et al., 2012, Kraljic et al., 2017, Nicoletti et al., 2014).

Moreover, it was a surprising result that scans obtained from physicians showed a higher overall pass rate compared to nurses, as in other studies, hand hygiene compliance was repeatedly reported to be better in nurses (Szilagyi et al., 2013). However, studies on compliance mostly provide little information on the quality of hand antisepsis. Reasons for our observation may be multifarious: while day shifts of physicians end after 8 hours, nurses have to stay for 12.5 hours. Consequently, during a sequence of several shifts, rest periods are shorter for nurses, and the re-increased compliance after longer breaks as shown by Dai et al. might be weakened in this setting (Dai et al., 2015).

Indeed, at the end of 25h shifts, the predicted probability of physicians for passing the hand scan was similar to the one of nurses at the beginning or end of night shifts, possibly showing an effect of sleep deprivation and circadian rhythm. In numerous prospective observational studies on nurses in the USA (Nurses´ Health Study), the group by Schernhammer et al. has shown that rotating shift work imposes circadian stress and is linked to the risk of several chronic diseases (Devore et al., 2013, Gu et al., 2015, Ramin et al., 2015, Schernhammer et al., 2001, Schernhammer and

Thompson, 2011, Vetter et al., 2018, Vetter et al., 2015). Disruption of the circadian rhythm, long working hours and sleep deprivation have been shown to be associated with changes of alertness, cognitive efficiency, temporal memory and attentional processes in healthy adults and night shift workers (Harrison and Horne, 2000, Kim et al., 2001, Rouch et al., 2005). For example, two cross-sectional surveys among nurses reported an association between long working hours and shift work with higher rates of work-related injuries (Lo et al., 2016, Stimpfel et al., 2015). These studies implicate the effect of circadian rhythm on cognitive performance, potentially suggesting that repeated disruption could have an impact on concentration and might be associated with decreased hand hygiene compliance and quality.

It has been shown earlier that visual feedback on individual hand hygiene performance, as provided by the Semmelweis Scanner, can help users to reduce the rate of inadequate hand disinfection (Helder et al., 2010, Lehotsky et al., 2015, Scheithauer et al., 2012). Future studies will have to address whether routine use of the Semmelweis Scanner by healthcare professional teams results in reductions of healthcare-associated infection rates in neonatal intensive care units.

Limitations

Among the technical limitations, it shall be noted that a special, ultraviolet dye labelled alcohol-based hand rub is necessary to be recognized by the Semmelweis Scanner. Therefore, all participants were aware of the up-coming measurements with the Semmelweis Scanner, which may have biased hand hygiene performance. Moreover, we did not collect data on workload on the respective days where scans were performed, and therefore could not examine the potential association between hand antisepsis performance and overall workload. Finally, we did not consider individual shift patterns of participants, e.g., number of night shifts or extended work

hours per week. Further, it has to be noted that in order to avoid any bias caused by the residual UV marker, scans had to be separated by 24 hours at least. Consequently, pre and post shift scans had to be done on different days, and subsequently linked to different shifts.

Author contribution statment

Judith Rittenschober-Böhm: conceptualization, investigation, data curation, writing original draft, project administration, funding acquisition; **Katharina Bibl**: investigation, data curation; **Michael Schneider**: investigation, data curation; **Romana Klasinc**: conceptualization, writing – review and editing; **Péter Szèremy**: methodology, software, formal analysis; **Tamas Haidegger**: methodology, software, formal analysis, resources; **Tamas Ferenci**: methodology, formal analysis, writing original draft; **Michaela Mayr**: investigation, data curation; **Angelika Berger**: conceptualization, writing – review and editing, supervision, funding acquisition; **Ojan Assadian**: conceptualization, formal analysis, writing – review and editing, supervision;

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interest: P.S. and T.H. are employed by HandinScan Zrt. The other

authors declare no conflicts of interest.

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Conclusion

In this study, the quality of hand antisepsis was inversely associated with extended working hours, potentially reflecting an increased lack of concentration and consequently discontinuities in hand antisepsis at the end of prolonged shifts in physicians and nurses working in a neonatal intensive care unit. This observation may support the call for shorter shift durations in order to decrease stress and increase patient safety. Alternatively, raising the awareness for hand antisepsis failure and most frequently missed areas of hand surface coverage may be beneficial. Whether continuous feedback on individual hand antisepsis performance, as provided by the Semmelweis Scanner, has a positive effect on patient safety, will have to be tested in future studies.

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Figure captions:

Fig 1: Defined regions of hand surface as analysed by the Semmelweis Scanner. Hand surfaces (palm and dorsum of left and right hand, respectively) are divided into 10 regions (0-9) each to analyse most frequently missed areas of hand antisepsis.

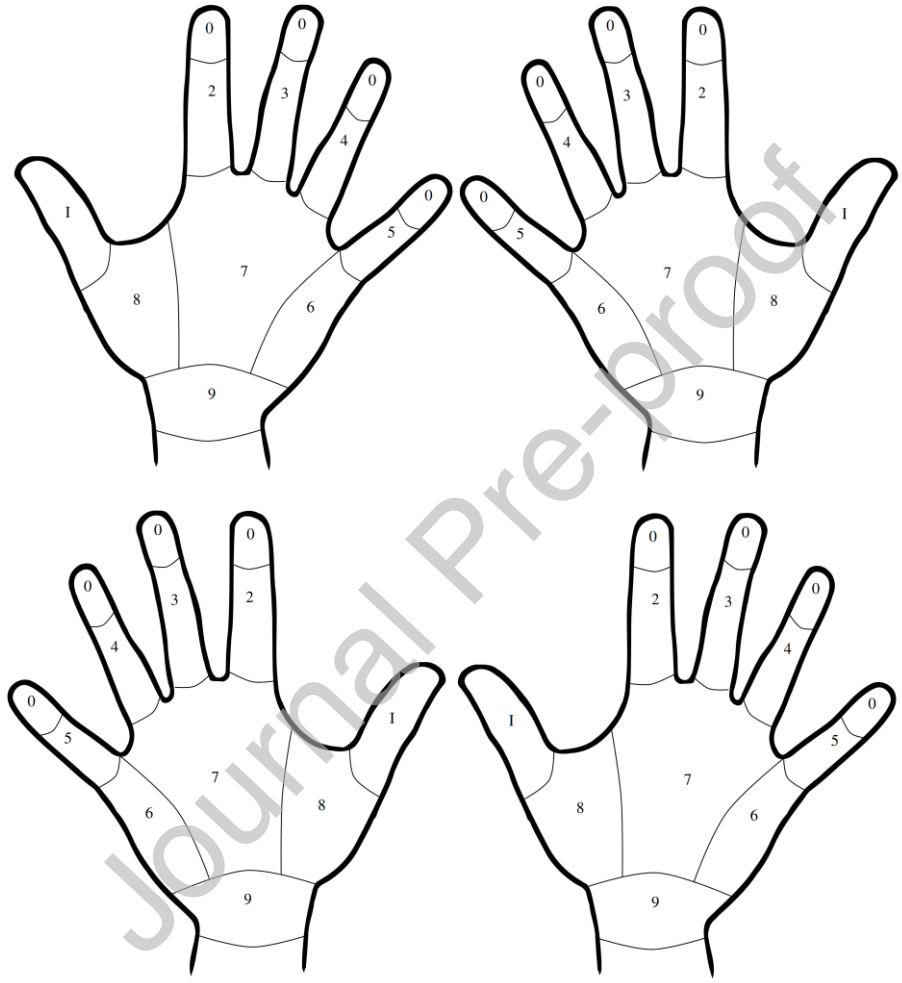


Fig 2: Estimated probabilities of achieving appropriate hand antisepsis quality (minimum 97%) according to the type of measurement (before or after shift, type of shift), per occupation

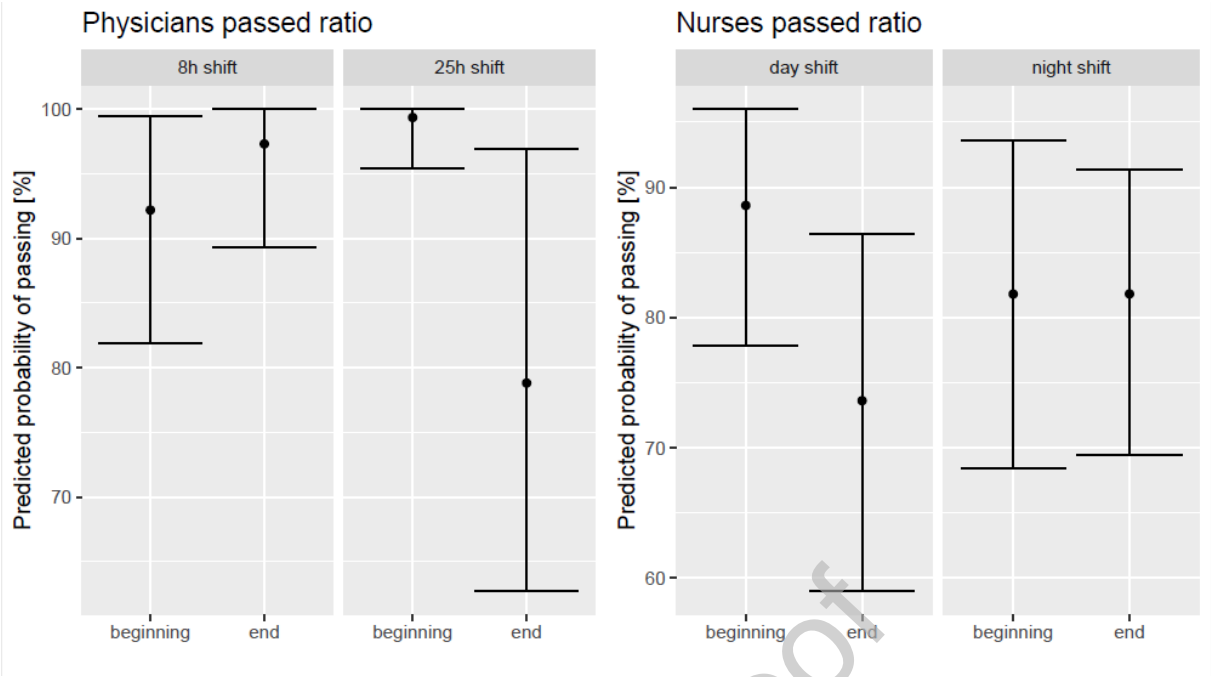


Fig 3: Ranking of hand antisepsis performance at the beginning and end of shifts

The total hand coverage of each healthcare worker was ranked from 1 to n both at the beginning and at the end of shifts. 100% results are categorized as 1.

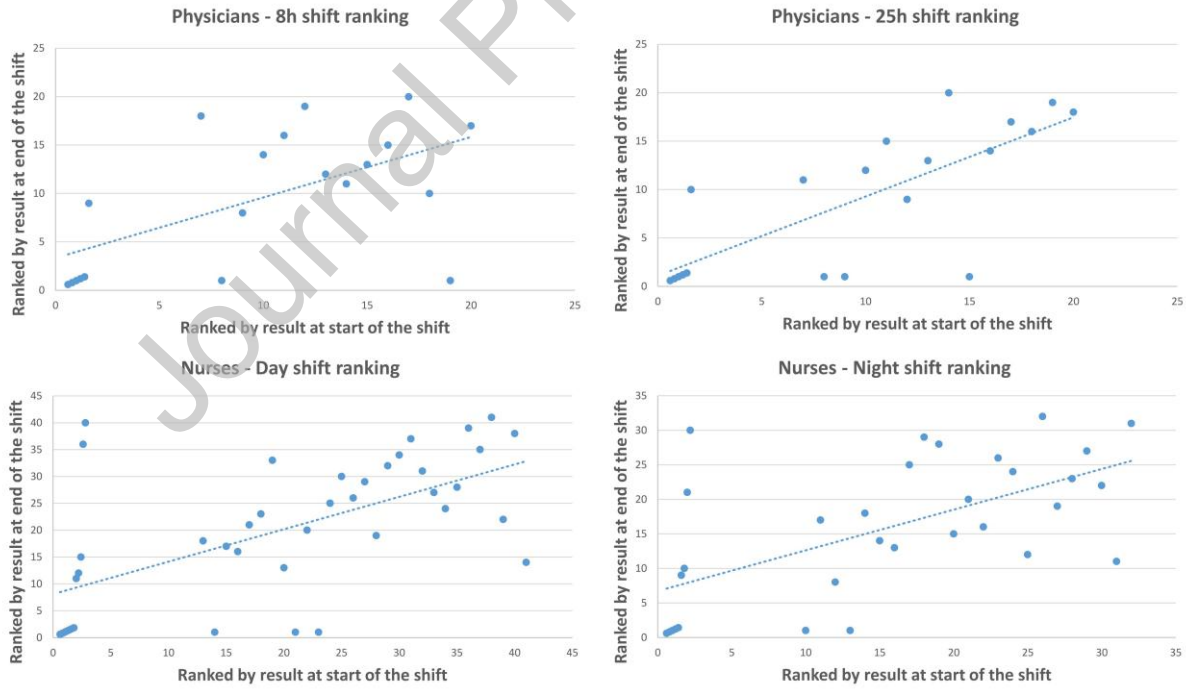
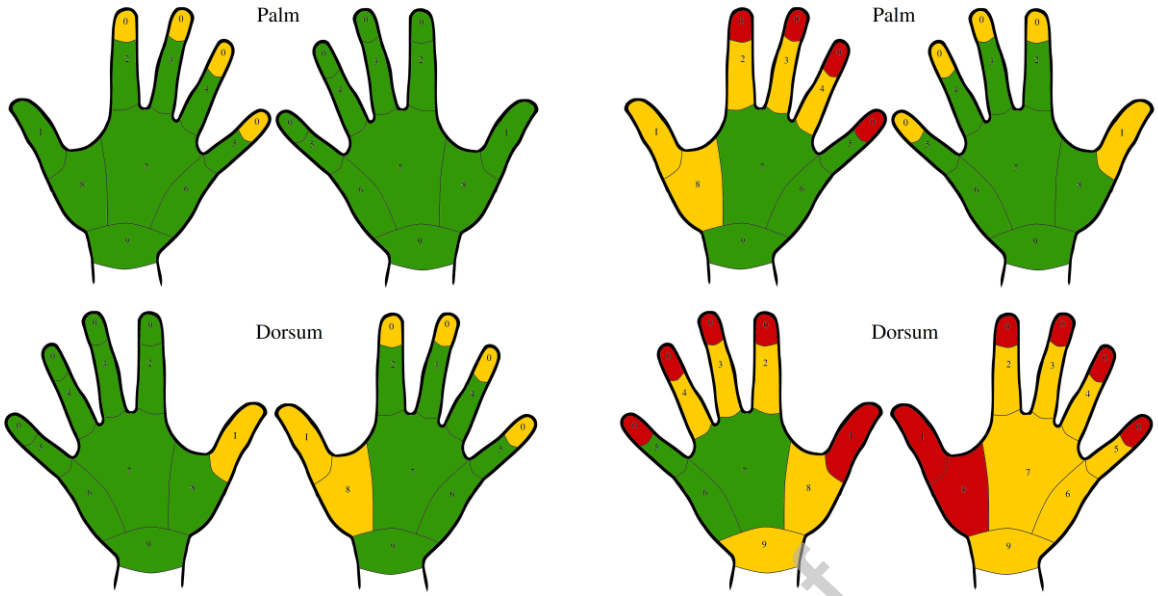


Fig 4: Distribution of errors in hand antisepsis linked to hand surface regions

Colour coded distribution of errors in hand rub coverage out of the total number of measurements, grouped by occupation (a, physicians; b, nurses). Red – most frequently missed: over 10%. Yellow - frequently missed: 5-10%. Green - less frequently missed: under 5%



a) b)

Caption for supplemental material:

Table S1 supplemental material: Most frequently missed areas of hand antisepsis

Occurrence of errors in hand rub coverage per hand region, shown as total number and percentage of all scans performed, per occupation.

Red – most frequently missed: over 10%. Yellow - frequently missed: 5-10%. Green - less frequently missed: under 5%