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Short report

Towards objective hand hygiene technique assessment: validation of the ultraviolet-dye-based hand-rubbing quality assessment procedure

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SUMMARY

Ultraviolet spectrum markers are widely used for hand hygiene quality assessment, although their microbiological validation has not been established. A microbiology-based assessment of the procedure was conducted. Twenty-five artificial hand models underwent initial full contamination, then disinfection with UV-dyed hand-rub solution, digital imaging under UV-light, microbiological sampling and cultivation, and digital imaging of the cultivated flora were performed. Paired images of each hand model were registered by a software tool, then the UV-marked regions were compared with the pathogen-free sites pixel by pixel. Statistical evaluation revealed that the method indicates correctly disinfected areas with 95.05% sensitivity and 98.01% specificity.

Introduction

Hand hygiene is an efficient and cost-effective tool for hospital infection prevention, substantially contributing to health quality assurance and patient safety [1]. The hands of hospital staff become contaminated involuntarily during patient care, thus becoming responsible for 20–40% of hospital infections [2]. Disinfecting hands with alcohol-based hand rub

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(ABHR) greatly reduces the transfer of pathogens [3], yet the hand-hygiene-related behaviour of staff is not adequate [4], and their hand-rubbing technique is well below standards [5]. The most widely used assessment and training method for hand hygiene technique is based on ultraviolet (UV)-dyed ABHR solutions, as these monitor the marker's distribution under UV light. However, the literature does not disclose any proper studies investigating the correlation between the UV-marked and correctly disinfected regions of the hands.

Some previous, limited studies validated the microbiological effect of ABHR application by the glove juice technique [6,7]. Glove juice technique is not specific for hand regions, thus unable to provide any information about the correlation of ABHR-treated areas and the reduction of microbiological contamination on the specific parts of the hand. Our main goal was to provide empirical and statistical proof that the distribution of ABHR on the hand surface corresponds to the disinfected areas.

Methods

Data collection

Artificial hand models (AHMs) designed especially for this study underwent the following procedure:

1. AHMs were created to mimic the human palm surface. Models consisted of hand-shaped objects cut from a polymethylmethacrylate plate and covered by prepared cow leather, to provide the bacteria an environment that is similar to the human hand. The size of the hand models was chosen to fit into a standard 90 mm Petri dish.
2. AHMs were disinfected with ABHR (Sterillium, Paul Hartmann AG, Hamburg, Germany), to remove the initial flora.
3. The AHMs' leather surface received homogeneous contamination using *Staphylococcus epidermidis* (strain ATCC 12228) bacteria, via dipping into bacterial suspension of 0.5 McFarland concentration. This pathogen is present in the normal flora of the human hand skin, and does not cause symptoms even in the case of high concentration. Having reached the 'totally infected' state of the AHMs, it means that their surface is uniformly covered by the pathogen.
4. UV-dyed ABHR solution (Visirub + Sterillium, Paul Hartmann AG) was applied to previously defined areas of the AHMs' surface. Regions of various shapes were considered for different AHM items. The disinfected area varied between 10% and 25% of the total surface.
5. Sixty seconds contact time was allowed for the ABHR, then digital images of the AHMs were taken under UV light, using the Semmelweis Scanner (HandInScan Zrt., Debrecen, Hungary) [8], to record the distribution of the UV marker on the investigated surface.
6. A full-size microbiological sample of the leather surface of each AHM was taken using a blood agar plate. Samples were incubated for 48 h at 37°C temperature, according to standard cultivation protocols. When the cultivation time elapsed, pictures of the cultivated samples were taken with a high-resolution digital camera.
7. All digital images were segmented with custom-developed software under expert supervision. In the case of the UV-light images, software-based segmentation of the light and dark areas was performed. These correspond to adequate and non-adequate ABHR coverage, respectively. In the digital images of cultivated bacteria, regions rich in and free from bacterial colonies were separated with the segmentation software using intensity- and texture-based criteria.
8. Corresponding pairs of pictures, formed of one picture taken under UV light (step 5) and the picture of the cultivated sample (step 6), were fed to rigid image registration, thus obtaining a two-way pixel-to-pixel mapping between the two images. This mapping enabled us to statistically evaluate the extent to which pathogen-free regions matched the UV-marked areas of the AHM.
9. During statistical analysis, the images obtained from microbiological cultivation were considered the ground truth (GT). The hypothesis under investigation was whether the regions of the AHM adequately covered by the UV dye matched the pathogen-free regions.

Steps 2–6 were performed under institutional approval in the premises of the Institute of Medical Microbiology, Semmelweis University (Budapest, Hungary), in December 2015.

Data analysis

Pairs of images were compared under the following terms. The picture of the cultivated flora was considered to be the GT, containing pathogen-free (positive, or adequately decontaminated) and contaminated (negative, or non-adequately decontaminated) areas. In the UV images, we considered positive the glowing areas, covered by the UV-dyed solution, and negative all other areas of the AHM. Consequently, true positives (TP) are pixels that glow under UV light and have their corresponding pixel free from pathogens according to the GT. False positives (FP) are pixels that appear bright under UV light, and their corresponding pixel is contaminated in the GT. False negatives (FN) are pixels that do not glow under UV light and their corresponding pixel is free from pathogens in the GT. True negatives (TN) are pixels that do not glow under UV light and their corresponding pixel is contaminated in the GT. Sensitivity, also known as true positive rate (TPR), is defined as $TPR = TP/(TP + FN)$. Specificity, also known as true negative rate (TNR), is defined as $TNR = TN/(TN + FP)$. Dice score (DS) is given by $DS = (2TP)/(2TP + FN + FP)$, and characterizes the global accuracy, taking into consideration all mismatches. Areas were assessed pixel by pixel, and finally were converted into percentage of the total area of the AHM. The statistical analysis was performed using R, version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Twenty-five different AHMs were included in the study. Each AHM was partially disinfected with the UV-dyed ABHR solution. The shape of the disinfected areas varied among AHMs, making them easily identifiable. The area of the disinfected spot was typically 15–20% of the AHM's total area. The coverage of each AHM was evaluated separately. The results of the software-based, pixel-level assessment were determined in the form of TP, TN, FP, and FN percentage of pixels within the segmented hand areas. The summary statistics of the evaluation are