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Research article

Effect of an acrylic terpolymer barrier film beneath transparent catheter dressings on skin integrity, risk of dressing disruption, catheter colonisation and infection ☆

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ABSTRACT

Objectives: We assessed the effect of a skin-protective terpolymer barrier film around the catheter insertion site on frequency of dressing disruptions and skin integrity issues (hyperaemia, skin irritation, residues of adhesives and moisture under the dressing). Secondary outcomes included colonisation of the central venous catheter (CVC) and rates of central line-associated bloodstream infection.
Research methodology: A monocentric, open-label, randomised controlled trial was performed comparing a control group receiving standard transparent catheter dressings without the skin-protecting barrier film and an intervention group receiving a transparent chlorhexidine-impregnated dressing with use of the skin-protective acrylic terpolymer barrier film (3M™ Cavilon™ No - Sting Barrier Film, 3 M Health Care, St. Paul, MN, USA).
Results: Sixty patients were enrolled and randomised in the study accounting for 60 central venous catheters and a total of 533 catheter days. Dressing disruptions occurred more frequently and at sooner time point in the control group. Skin integrity issues were significantly less observed in the intervention group. No differences in CVC colonisation or central line-associated bloodstream infection were observed.
Conclusions: The application of a barrier film creating a skin-protective polymer layer beneath transparent catheter dressings is associated with less dressing disruptions and skin integrity issues without altering the risk of infectious complications if used in combination with a chlorhexidine-impregnated catheter dressing.

Implications for clinical practice

- Catheter dressing disruptions and skin integrity issues such as hyperaemia at the insertion or skin irritations are associated with an increased risk of catheter colonisation and subsequent infection.
- Chlorhexidine-impregnated catheter dressings protect against central line-associated bloodstream infection.
- Application of an acrylic terpolymer skin-protective barrier film around the catheter insertion site results in less dressing disruptions and less skin integrity issues while not altering the risk of catheter colonisation or infection, at least not when used in combination with a chlorhexidine-impregnated catheter dressing.

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Introduction

Bloodstream infections represent an important source of infectious morbidity in critically ill patients as they rank third among all nosocomial infections (Agbaht et al., 2007; Blot et al., 2009; Vincent et al., 2009; Tabah et al., 2012; Dimopoulos et al., 2013). About one third of nosocomial bloodstream infections are related to the insertion of intravascular catheters, mostly central line-associated bloodstream infection (CLABSI)(Safdar et al., 2002; Blot et al., 2003). Pooled estimates of mean occurrence rates of CLABSI are 4.4 CLABSI per 100 devices inserted (95% confidence interval [CI] 4.1-4.9) and 2.7 CLABSI per 1000 catheter days (95% CI 2.6–2.9)(Maki et al., 2006). In addition, CLABSI carry a substantial economic burden through an added length of hospitalisation and excess hospital costs (Blot et al., 2005; Warren et al., 2006; Higuera et al., 2007; Schwebel et al., 2012). As a consequence a variety of measures to prevent CLABSI are advocated. These include educational initiatives and use of care bundles or checklists to optimise adherence with local recommendations, optimal catheter insertion site selection, maximal sterile barriers during catheter insertion, adequate disinfection of the insertion site and use of chlorhexidine gluconate (CHG)-impregnated washcloths for daily bathing (Hu et al., 2004; Labeau et al., 2008, 2009; Blot et al., 2014a; Afonso et al., 2016; Arvaniti et al., 2016; Labeau et al., 2016; Mimoz et al., 2016; Arvaniti 2017). Recently, the use of CHG-impregnated dressings have demonstrated to significantly reduce the risk of catheter infections (Timsit et al., 2012b). Notwithstanding this innovative dressing, accidental dressing disruptions remain a particular risk factor for CLABSI (Timsit et al., 2012a). Timsit and colleagues demonstrated that the risk for CLABSI increased exponentially with the number of dressing disruptions: a hazard ratio (HR) of 1.2 (95% confidence interval [CI] 0.5–7.5) for a first disruption, a HR 3.3 (95% CI 1.2–9.0) for a second disruption, and a 12.5 HR (95% CI 4.0–39.6) for a third dressing disruption. Therefore, dressings are designed to have an adequate adhesive potential. However, this includes a potential risk of skin breakdown that, on its turn, is a risk factor for CLABSI as well because skin lesions contain a substantial number of potentially pathogenic microorganisms. In order to avoid adhesives-related skin breakdown a skin product has been developed creating a polymer protective film. This film-forming liquid acrylate proved valuable to protect integrity of the peri-wound skin in chronic ulcers (Schuren et al., 2005). To the best of our knowledge however, this barrier film has never been used to protect the skin from adhesive catheter dressings. In addition, it is uncertain to which extent the use of such a barrier film affects the adhesive potential of the catheter dressings. Furthermore, it is uncertain whether the application of this barrier film facilitates CVC colonisation.

The objective of this study is to compare the standard use of transparent dressings with transparent CHG-impregnated catheter dressings with use of a skin-protective barrier film. Primary outcomes were skin integrity and risk of dressing disruption. Secondary outcomes were rates of central venous catheter (CVC) colonisation rates and CLABSI rates.

Methods

Setting

The study was executed during a five months period (August to December 2014) in a specialised 12-bed intensive care unit (ICU) for patients with infectious diseases or septic complications at the Pirogov National Medical Surgical Center, Moscow. The local ethics committee approved the study and informed consent was required either from the patient or a legal representative if the patient was unable to do so prior to study enrollment. In the latter case, the patient was informed at a later stage and asked if he/she concurred with the using the data for research purposes. The study data are reported according to the Consolidated Standards of Reporting Trials (CONSORT) statement.

Study design

A monocentric, open-label, randomized, controlled trial was conducted to compare standard transparent dressings with transparent CHG-impregnated catheter dressings (3 M Tegaderm CHG™, 3 M Health Care, St. Paul, MN, USA). In addition, in the CHG-dressing group the patients' skin was treated with a liquid film-forming acrylate (Cavilon™ "No Sting Barrier Film", 3 M Health Care, St. Paul, MN, USA). The barrier film was applied on the skin area immediately around the CVC insertion site. As such the study resulted in a control group of patients with standard transparent polyurethane CVC dressings and an intervention group with CHG-impregnated transparent polyurethane CVC dressings with use of the skin protective ointment. Patients were randomised following a random number generator.

Patient selection and follow-up

Besides informed consent, patients were eligible for study inclusion when they were adult (≥16 years of age), had a clinical indication for central venous catheterisation and an anticipated length of catheter indwelling time of seven days. Exclusion criteria included known allergy to chlorhexidine or dressing adhesives. Patients were randomised to the control or the intervention group before CVC insertion and follow-up of the patients lasted until CVC removal. Patients could only be included once in the trial.

Outcomes

Primary outcomes were average dressing dwell time, number of dressing disruptions and skin integrity. Skin integrity was judged upon the following observations: (i) hyperaemia of the insertion site, (ii) presence of skin irritations under the dressing, (iii) residues of adhesives on the skin and (iv) moisture under the dressing. In dressing disruptions we considered either partial or full dressing disruptions. Partial dressing disruption is defined as loosening of the dressing without revealing the CVC insertion site, while full dressing disruption is defined as loosening of the dressing leaving the CVC insertion site uncovered.

Secondary outcomes included observations associated with either inflammation or infection, i.e. presence of discharge from the insertion site, CVC colonisation rates and CLABSI rates. After removal the CVCs the catheter tips were evaluated for colonisation by semiquantitative (roll-plate) culture (Maki et al., 1977). Hereby, catheter colonisation was defined as a microbial growth of >15 colony forming units (Mermel et al., 2009). As we evaluated the efficacy of dressings, only the external surface of the catheter was evaluated for microbial colonisation.

Patient characteristics

Data were collected in order to compare patient characteristics between the two groups. These included demographics, concomitant medication, underlying conditions and aspects reflecting severity of acute illness. For the latter we reported the acute physiology and chronic health evaluation (APACHE) II score and the sequential organ failure assessment (SOFA) score (Knaus et al., 1985; Vincent et al., 1996). Furthermore, the need for organ support either at the time of study enrollment or during the complete study course was

reported. These included the need for mechanical ventilation, renal replacement therapy and vasopressors or inotropes.

Standard care

Standard catheter care included alcohol-based antiseptic (0.5% chlorhexidine in 70% ethanol) for skin preparation before CVC insertion, maximal sterile barriers including broad coverage of the patients with sterile drapes, and use of sterile gowns and gloves of the operator, mask and hat. After the insertion procedure, the CVC was covered with either the standard transparent dressing or the CHG-dressing according to the result of the randomisation process. Catheter dressings were changed every seven days, or in case of full dressing disruption or if moisture was present under the dressing. Dressings were not changed in case of partial dressing disruption provided the coverage of the insertion site.

Statistics

Descriptive variables are reported as n (%) or mean (standard deviation) and median (interquartile range). Comparisons between the study groups are executed with the Mann Whitney *U* test or Fisher Exact test as appropriate. Colonisation and CLABSI rates are expressed per 1000 CVC days. The Kaplan-Meier method with a log-rank test was used to compare survival curves of both treatment groups describing time until first dressing disruption. Statistical significance is defined as $p < 0.05$.

Results

Patient population

Fig. 1 describes the study flow diagram. Sixty patients were enrolled in the study accounting for 60 CVCs and a total of 533 CVC days. No patients were excluded during the study and no patient was lost to follow up. Characteristics of patients with standard and CHG-dressings are shown in Table 1. No important differences were observed between the two groups in gender, age, CVC insertion site and dwell time, use of concomitant therapy, underlying conditions and severity of disease as assessed by organ failure and the need for organ support. All CVCs used were triple-lumen catheters. Reasons for CVC removal were not different between the groups and included no further need for a CVC (n = 28), clinically suspected CLABSI (n = 19), mortality (n = 7), and planned CVC change because of the need to initiate renal replacement therapy (n = 5).

Primary outcomes

Outcomes are reported in Table 2. Dressing dwell time was significantly higher in the intervention group. Main reasons for dressing changes included full dressing disruptions and moisture beneath the dressing, which were more commonly observed in the control group. Fig. 2 describes the Kaplan-Meier survival curves comparing the time until the first dressing disruption. Dressing

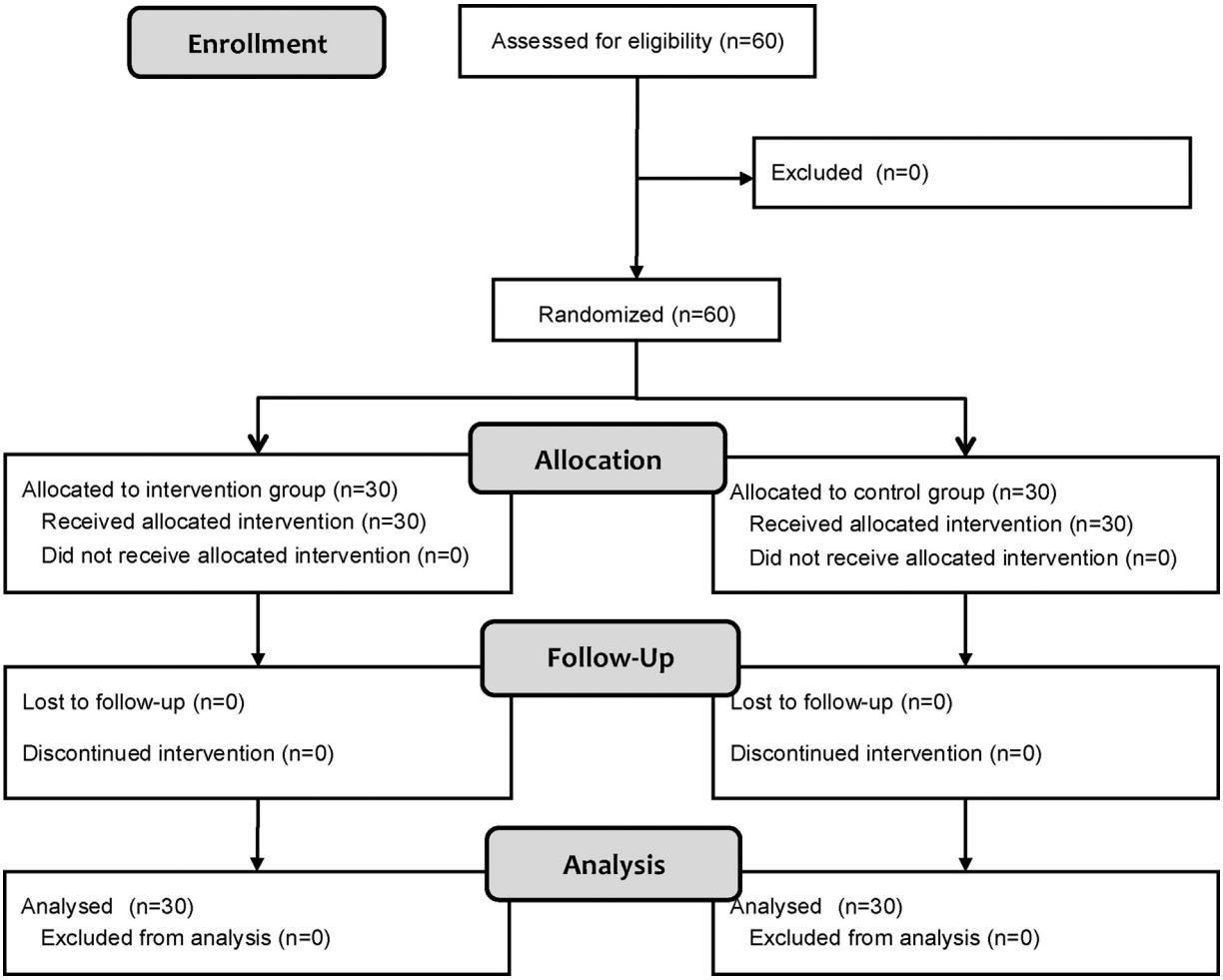

Fig. 1. Study flow diagram.

Table 1
Characteristics of study groups.

Feature	Control group, Standard transparent dressing without skin-protective barrier film (n = 30)	Intervention group, Transparent CHG-dressing with skin-protective barrier film (n = 30)	p
Demographics			
Male gender	14 (46.7)	12 (40.0)	0.795
Age, years	64 (56–73)	65.5 (56–69)	0.708
Length of hospital stay before enrollment, days	6.0 (1.25–10.5)	3.5 (2–6.75)	0.406
Catheter insertion site			
Subclavian vein	16 (53.3)	17 (56.7)	>0.999
Internal jugular vein	14 (46.7)	13 (43.3)	>0.999
Catheter dwell time, days	8.0 (4.0–10.0)	9.5 (7.0–12.0)	0.108
Concomitant therapy			
Antibiotic therapy	16 (53.3)	17 (56.7)	0.999
Glucocorticosteroid therapy	1 (3.3)	0	>0.999
Chemotherapy	1 (3.3)	0	>0.999
Parenteral nutrition,			
At time of enrollment	5 (16.7)	1 (3.3)	0.195
During study course	6 (20.0)	4 (13.3)	0.731
Underlying conditions			
Diabetes mellitus	1 (3.3)	2 (6.7)	>0.999
Chronic obstructive pulmonary disease	1 (3.3)	4 (13.3)	0.202
Hypothyroidism	0	3 (10.0)	0.237
Severity of acute illness			
Sepsis at time of enrollment	5 (16.7)	3 (10.0)	0.480
APACHE II score	17.5 (14–23)	16 (14–23)	0.904
SOFA score	3 (2–5)	4 (3–7)	0.182
Need for organ support at study enrollment			
Mechanical ventilation	15 (50.0)	22 (73.3)	0.110
Renal replacement therapy	2 (6.7)	5 (16.7)	0.424
Vasopressors/inotropes	6 (20.0)	9 (30.0)	0.552
Mechanical ventilation	15 (50.0)	24 (80.0)	0.029
Renal replacement therapy	4 (13.3)	7 (23.3)	0.506
Vasopressors/inotropics	7 (23.3)	12 (40.0)	0.267

Data is reported as median (interquartile range) for continuous variables and n (%) for discrete variables. CHG, chlorhexidine gluconate impregnated; APACHE, acute physiology ad chronic health evaluation; SOFA, sequential organ failure assessment.

Table 2
Study outcomes in patients with standard transparent dressings vs. transparent CHG-impregnated dressings with the use of a lotion creating a skin-protective polymer film.

	Control group, Standard transparent dressing without skin-protective barrier film (n = 30)	Intervention group, Transparent CHG-dressing, with skin-protective barrier film (n = 30)	p
Primary outcomes			
Dressing dwell time, days	2.5 (1.0–3.0)	7.0 (6.0–7.0)	<0.001
Dressing disruptions			
Partial	4 (13.3)	7 (23.3)	0.506
Full	17 (56.7)	2 (6.7)	<0.001
Skin integrity			
Hyperaemia of the insertion site	4 (13.3)	1 (3.3)	0.353
Presence of skin irritations	1 (3.3)	0	>0.999
Residues of adhesive on skin	0	0	>0.999
Moisture under the dressing	6 (20)	0	0.009
All skin integrity issues	11 (36.7)	1 (3.3)	0.001
Secondary outcomes			
Presence of discharge from the insertion site	2 (6.7)	0	0.492
CVC colonisation	9 (30.0)	11 (36.7)	0.785
CLABSI	5 (16.7)	2 (6.7)	0.424

Data is reported as median (interquartile range) for continuous variables and n (%) for discrete variables. CHG, chlorhexidine gluconate impregnated; CVC, central venous catheter; CLABSI, central line-associated bloodstream infection.

disruption occurred more frequently and at a sooner time point in the control group (Log rank test: $p < 0.001$).

Overall skin integrity issues were more commonly observed in the control group ($p = 0.001$). This significant difference could mainly be attributed to the presence of moisture under the dressing and hyperaemia at the insertion site.

Secondary outcomes

Discharge from the CVC insertion site was only observed in two cases in the control group. All CVCs were cultured. Rates of CVC colonisation or infection per patient numbers are reported in Table 2. In addition, we calculated these infectious indices per 1000 catheter days. Rates of CVC colonisation were not different (37.9/1000 CVC days in the intervention group vs. 37.0/1000 CVC days in the control arm [relative risk 1.22, 95% confidence interval 0.59–2.5]) as were CLABSI rates (6.9/1000 vs. 20.6/1000 CVC days [relative risk 0.4, 95% confidence interval, 0.08–1.9]).

Discussion

In this randomised controlled trial we assessed the value of a barrier film creating a polymer skin-protective layer around the catheter insertion site on dressing disruptions and skin integrity.

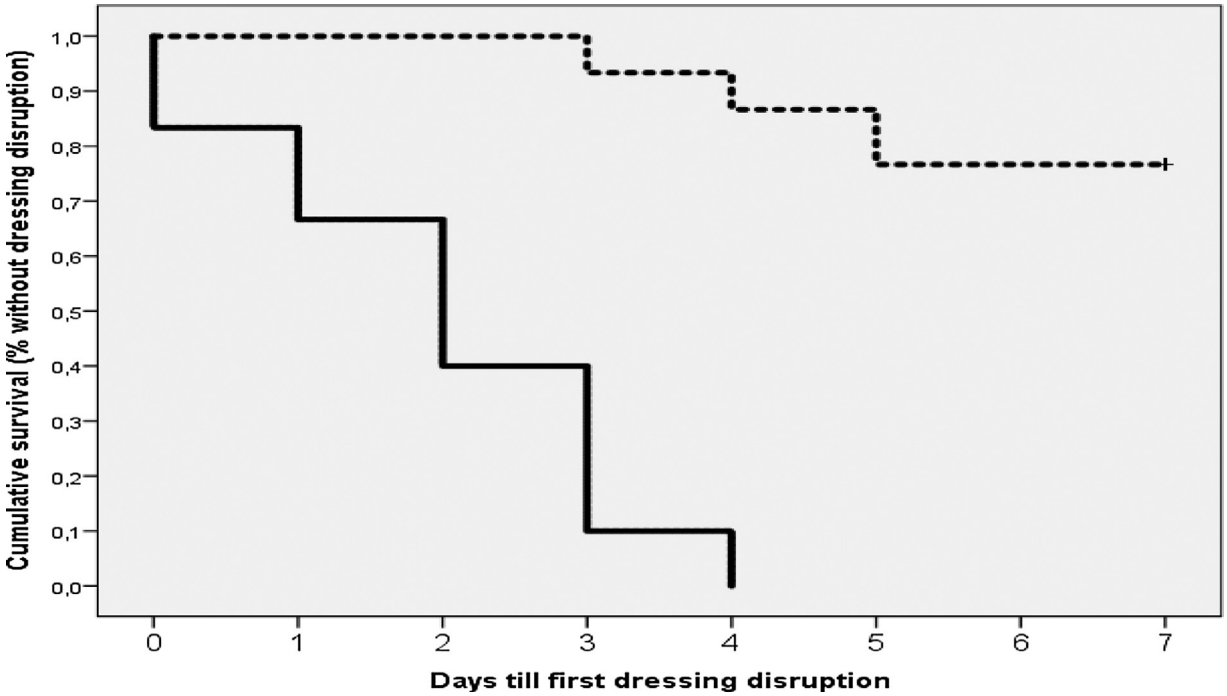

Fig. 2. Survival curves describing time till first dressing disruption.The solid line represents the control group (standard transparent dressing) and the dashed line represents the intervention group (transparent chlorhexidine-impregnated catheter dressing with use of a product creating a skin-protective polymer film). Log rank test: $p < 0.001$

Catheter colonisation and CLABSI rates were secondary outcomes. Dressing disruptions as well as skin integrity issues occurred more frequently in the control group.

This finding is important as dressing disruptions as well as skin breakdown in the immediate surrounding of the insertion site are potential risk factors for CVC colonisation and subsequent infection (Timsit et al., 2012a). While Cavilon® skin barrier film has been proved successful in maintaining integrity of the peri-wound skin, as far as we know it has not been evaluated beneath catheter dressings. As such it remained uncertain what the effect of this barrier film would be on likelihood of dressing disruptions and infectious complications. An absolute decrease in CLABSI rates was observed, but the study lacked power to demonstrate statistical significance. This non-significant reduction in CLABSI risk can be attributed to the fact that a CHG-dressing was used in the intervention group. This dressing significantly reduced CLABSI risk in a large multicenter randomised controlled trial and these results were later on confirmed in a meta-analysis including nine randomised studies (Timsit et al., 2012b; Safdar et al., 2014). While a favorable effect of the barrier film in terms of skin integrity could be expected based on previous studies, and albeit that skin integrity has a negative effect on the risk of CVC colonisation/infection, it remained uncertain whether the use of this barrier film in the immediate zone of the insertion site could have increased the risk of infectious complications. Based on our observations we can state that the use of a product creating a polymer skin-protective film does not negatively influence the risk of catheter infection, at least not when used in combination with a CHG-impregnated catheter dressing.

We must recognise that CLABSI rates in our study were high with rates of about 7/1000 and 20/1000 CVC days in the intervention group and the control group, respectively. In a systematic review of quality improvement initiatives to reduce the risk of CLABSI, six studies were identified with a baseline CLABSI rate >15/1000 CVC days (Blot et al., 2014a). Our study must be situated within this range. The high CLABSI rate might be partially explained by the specific patient population as the study was conducted in an ICU specialised to treat patients suffering from infectious complications. In addition, the cohort was older with about a quarter of patients aged over 70 years and high occurrence rates of organ failure. Older age as well as multiple organ failure are well-recognized risk factors for infectious complications in general (Blot and Vandewoude 2004; Vandewoude et al., 2004; Reynvoet et al., 2009; Reunes et al., 2011; Blot et al., 2014b; Sousa et al., 2017). Furthermore, the standard nurse-to-patient ratio is 1:3 while nursing shifts last for 24 hours. Especially the latter contributes to an excessive workload which is associated with sub-optimal compliance with recommendations in infection prevention and indicated as a main barrier to comply with local protocols in ICUs (Rello et al., 2002; De Wandel et al., 2010; Lambert et al., 2013; Valencia et al., 2016; Battistella et al., 2017; De Wandel 2017; Piras et al., 2017; Sadule-Rios and Aguilera 2017; Velasquez Reyes et al., 2017).

Limitations

This study has limitations. As already mentioned the sample size was not powered for detecting differences in CLABSI rates. Moreover, the fact that two different dressing were used makes an evaluation of infectious complications at the catheter site difficult. Because two interventions were combined in the intervention group it is not possible to evaluate the value of the acrylic terpolymer barrier film in combination with a standard polyurethane dressing. As such it is, at least theoretically, possible that the application of the barrier film increases the risk of CVC colonisation, but that in this study this (unproven) deleterious effect has been erased by the use of a CHG-impregnated dressing in the intervention group. In the same line, we cannot rule out that the chlorhexidine gel pad absorbed small proportions of the barrier film, but this unlikely as the substance is compatible with CHG. This might have influenced the properties of the dressing and as such the outcomes. However, the skin-protective barrier film was carefully applied in the zone around the gel pad where the adhesive part

of the transparent dressing secures connection with the skin. As dressing disruption starts when these outer parts of the dressing loose contact with the skin, we believe that the eventual influence of combining the barrier film with the CHG-dressing only marginally might have impacted to study outcome. Finally, subsequent dressing disruptions were not recorded. However, the fact that only the first dressing disruption was considered is unlikely to change the final conclusion, i.e. the barrier film protects against accidental dressing disruptions.

Conclusion

The use of a skin product creating a polymer protective film beneath transparent dressings results in longer dressing dwell times and less skin breakdown. The application of the skin product does not alter the risk of CVC colonisation or CLABSI, at least not when used combined with a CHG-impregnated dressing.

Ethical statement

This study was approved by the ethics committee at the FGBU "NMHC of NI Pirogov" of the Ministry of Health of Russia (Protocol no. 3 of 4 June 2014). Address: Moscow, Nizhne Pervomaiskaya street 70. All patients or legal representatives gave informed consent for the study.

Conflicts of interest

- S. Blot received lecture fees from 3 M.
- I.V. Zhivoteva received lecture fees from 3 M.
- 3 M supported the study with the free provision of Tegaderm CHG dressing and Cavilon "No Sting Barrier Film" for research purposes only.

References

Afonso, E., Blot, K., Blot, S., 2016. Prevention of hospital-acquired bloodstream infections through chlorhexidine gluconate-impregnated washcloth bathing in intensive care units: a systematic review and meta-analysis of randomised crossover trials. Euro Surveill. 21 (November (46)), 30400.

Agbaht, K., Diaz, E., Muñoz, E., Lisboa, T., Gomez, F., Depuydt, P.O., et al., 2007. Bacteremia in patients with ventilator-associated pneumonia is associated with increased mortality: a study comparing bacteremic vs. nonbacteremic ventilator-associated pneumonia. Crit. Care Med. 35 (September (9)), 2064–2070.

Arvaniti, K., Lathyris, D., Blot, S., Apostolidou-Kiouti, F., Koulenti, D., Haidich, A.-B., 2016. Cumulative evidence of randomized controlled and observational studies on catheter-related infection risk of central venous catheter insertion site in ICU patients: a pairwise and network meta-analysis. Crit. Care Med., 1

Arvaniti, K., 2017. Preventing central venous line related bloodstream infections in adult ICUs: start from the basics and bundle. Intensive Crit. Care Nurs. 43, 3–5.

Battistella, G., Berto, G., Bazzo, S., 2017. Developing professional habits of hand hygiene in intensive care settings: an action-research intervention. Intensive Crit. Care Nurs. 38 (February), 53–59.

Blot, S., Vandewoude, K., 2004. Management of invasive candidiasis in critically ill patients. Drugs 64 (19), 2159–2175.

Blot, S., Vandewoude, K., Hoste, E., Colardyn, F., 2003. Reappraisal of attributable mortality in critically ill patients with nosocomial bacteraemia involving Pseudomonas aeruginosa. J. Hosp. Infect. 53 (Jan (1)), 18–24.

Blot, S.I., Depuydt, P., Annemans, L., Benoit, D., Hoste, E., De Waele, J.J., et al., 2005. Clinical and economic outcomes in critically ill patients with nosocomial catheter-related bloodstream infections. Clin. Infect. Dis. 41 (Dec (11)), 1591–1598.

Blot, S., Cankurtaran, M., Petrovic, M., Vandijck, D., Lizy, C., Decruyenaere, J., et al., 2009. Epidemiology and outcome of nosocomial bloodstream infection in elderly critically ill patients: a comparison between middle-aged, old, and very old patients. Crit. Care Med. 37 (May (5)), 1634–1641.

Blot, K., Bergs, J., Vogelaers, D., Blot, S., Vandijck, D., 2014a. Prevention of central line-associated bloodstream infections through quality improvement interventions: a systematic review and meta-analysis. Clin. Infect. Dis. 59 (April (1)), 96–105 (Oxford University Press).

Blot, S., Koulenti, D., Dimopoulos, G., Martin, C., Komnos, A., Krueger, W.A., et al., 2014b. Prevalence, risk factors, and mortality for ventilator-associated pneumonia in middle-aged, old, and very old critically ill patients*. Crit. Care Med. 42 (Mar (3)), 601–609.

De Wandel, D., Maes, L., Labeau, S., Vereecken, C., Blot, S., 2010. Behavioral determinants of hand hygiene compliance in intensive care units. Am. J. Crit. Care 19 (3), 230–239.

De Wandel, D., 2017. Key factors for hand hygiene promotion in intensive care units. Intensive Crit. Care Nurs. 42, 3–4.

Dimopoulos, G., Koulenti, D., Blot, S., Sakr, Y., Anzueto, A., Spies, C., et al., 2013. Critically ill elderly adults with infection: analysis of the extended prevalence of infection in intensive care study. J. Am. Geriatr. Soc. 61 (12), 2065–2071.

Higuera, F., Rangel-Frausto, M.S., Rosenthal, V.D., Soto, J.M., Castañon, J., Franco, G., et al., 2007. Attributable cost and length of stay for patients with central venous catheter-associated bloodstream infection in Mexico City intensive care units: a prospective, matched analysis. Infect. Control Hosp. Epidemiol. 28 (January (1)), 31–35.

Hu, K.K., Veenstra, D.L., Lipsky, B.A., Saint, S., 2004. Use of maximal sterile barriers during central venous catheter insertion: clinical and economic outcomes. Clin. Infect. Dis. 39 (November (10)), 1441–1445 (Oxford University Press).

Knaus, W.A., Draper, E.A., Wagner, D.P., Zimmerman, J.E., 1985. APACHE II: a severity of disease classification system. Crit. Care Med. 13 (10), 818–829.

Labeau, S., Vereecke, A., Vandijck, D.M., Claes, B., Blot, S.I., 2008. Executive Board of the Flemish Society for Critical Care Nurses. Critical care nurses' knowledge of evidence-based guidelines for preventing infections associated with central venous catheters: an evaluation questionnaire. Am. J. Crit. Care 17 (January (1)), 65–71 (quiz72).

Labeau, S.O., Vandijck, D.M., Rello, J., Adam, S., Rosa, A., Wenisch, C., et al., 2009. Centers for Disease Control and Prevention guidelines for preventing central venous catheter-related infection: results of a knowledge test among 3405 European intensive care nurses. Crit. Care Med. 37 (1), 320–323.

Labeau, S.O., Rello, J., Dimopoulos, G., Lipman, J., Sarikaya, A., Oztürk, C., et al., 2016. The value of E-Learning for the prevention of healthcare-Associated infections. Infect. Control Hosp. Epidemiol. 13 (May), 1–8.

Lambert, M.-L., Palomar, M., Agodi, A., Hiesmayr, M., Lepape, A., Ingenbleek, A., et al., 2013. Prevention of ventilator-associated pneumonia in intensive care units: an international online survey. Antimicrob. Resist. Infect. Control 2 (1), 9. BioMed Central Ltd..

Maki, D.G., Weise, C.E., Sarafin, H.W., 1977. A semiquantitative culture method for identifying intravenous-catheter-related infection. N. Engl. J. Med. 296 (June (23)), 1305–1309.

Maki, D.G., Kluger, D.M., Crnich, C.J., 2006. The risk of bloodstream infection in adults with different intravascular devices: a systematic review of 200 published prospective studies. Mayo Clin. Proc. 81 (September (9)), 1159–1171 (Elsevier).

Mermel, L.A., Allon, M., Bouza, E., Craven, D.E., Flynn, P., O'Grady, N.P., et al., 2009. Clinical practice guidelines for the diagnosis and management of intravascular catheter-related infection: 2009 Update by the Infectious Diseases Society of America. Clinical Infectious Diseases: An Official Publication of the Infectious Diseases Society of America, vol. 49. Oxford University Press, pp. 1–45.

Mimoz, O., Chopra, V., Timsit, J.-F., 2016. What's new in catheter-related infection: skin cleansing and skin antisepsis. Intensive Care Med.

Piras, S.E., Lauderdale, J., Minnick, A., 2017. An elicitation study of critical care nurses' salient hand hygiene beliefs. Intensive Crit. Care Nurs. 42, 10–16.

Rello, J., Lorente, C., Bodí, M., Diaz, E., Ricart, M., Kollef, M.H., 2002. Why do physicians not follow evidence-based guidelines for preventing ventilator-associated pneumonia?: a survey based on the opinions of an international panel of intensivists. Chest 122 (2), 656–661.

Reunes, S., Rombaut, V., Vogelaers, D., Brusselaers, N., Lizy, C., Cankurtaran, M., et al., 2011. Risk factors and mortality for nosocomial bloodstream infections in elderly patients. Eur. J. Intern. Med. 22 (October (5)), e39–e44 (Elsevier).

Reynvoet, E., Vandijck, D.M., Blot, S.I., Dhondt, A.W., De Waele, J.J., Claus, S., et al., 2009. Epidemiology of infection in critically ill patients with acute renal failure. Crit. Care Med. 37 (July (7)), 2203–2209.

Sadule-Rios, N., Aguilera, G., 2017. Nurses' perceptions of reasons for persistent low rates in hand hygiene compliance. Intensive Crit. Care Nurs. 42, 17–21.

Safdar, N., Kluger, D.M., Maki, D.G., 2002. A review of risk factors for catheter-related bloodstream infection caused by percutaneously inserted, noncuffed central venous catheters: implications for preventive strategies. Medicine (Baltimore) 81 (Novmber (6)), 466–479.

Safdar, N., O'Horo, J.C., Ghufran, A., Bearden, A., Didier, M.E., Chateau, D., et al., 2014. Chlorhexidine-impregnated dressing for prevention of catheter-related bloodstream infection: a meta-analysis*. Crit. Care Med. 42 (July (7)), 1703–1713.

Schuren, J., Becker, A., Sibbald, R.G., 2005. A liquid film-forming acrylate for peri-wound protection: a systematic review and meta-analysis (3 M Cavilon no-sting barrier film). Int. Wound J. 2 (September (3)), 230–238. Blackwell Science Ltd..

Schwebel, C., Lucet, J.-C., Vesin, A., Arrault, X., Calvino-Gunther, S., Bouadma, L., et al., 2012. Economic evaluation of chlorhexidine-impregnated sponges for preventing catheter-related infections in critically ill adults in the dressing study. Crit. Care Med. 40 (1), 11–17.

Sousa, A.S., Ferrito, C., Paiva, J.A., 2017. Intubation-associated pneumonia: an integrative review. Intensive Crit. Care Nurs. 42, 45–52.

Tabah, A., Koulenti, D., Laupland, K., Misset, B., Valles, J., Bruzzi de Carvalho, F., et al., 2012. Characteristics and determinants of outcome of hospital-acquired bloodstream infections in intensive care units: the EUROBACT international

cohort study. Intensive Care Med. 38 (December (12)), 1930–1945 (Springer-Verlag).
Timsit, J.-F., Bouadma, L., Ruckly, S., Schwebel, C., Garrouste-Orgeas, M., Bronchard, R., et al., 2012a. Dressing disruption is a major risk factor for catheter-related infections. Crit. Care Med. 40 (January (6)), 1707–1714.
Timsit, J.-F., Mimoz, O., Mourvillier, B., Souweine, B., Garrouste-Orgeas, M., Alfandari, S., et al., 2012b. Randomized controlled trial of chlorhexidine dressing and highly adhesive dressing for preventing catheter-related infections in critically ill adults. Am. J. Respir. Crit. Care Med. 186 (December (12)), 1272–1278. American Thoracic Society.
Valencia, C., Hammami, N., Agodi, A., Lepape, A., Herrejon, E.P., Blot, S., et al., 2016. Poor adherence to guidelines for preventing central line-associated bloodstream infections (CLABSI): results of a worldwide survey. Antimicrob. Resist. Infect. Control 5 (1), 49.
Vandewoude, K., Blot, S., Benoit, D., Depuydt, P., Vogelaers, D., Colardyn, F., 2004. Invasive aspergillosis in critically ill patients: analysis of risk factors for acquisition and mortality. Acta Clin. Belg. 59 (September (5)), 251–257 (Taylor & Francis).
Velasquez Reyes, D.C., Bloomer, M., Morphet, J., 2017. Prevention of central venous line associated bloodstream infections in adult intensive care units: a systematic review. Intensive Crit. Care Nurs. 43, 12–22.
Vincent, J.L., Moreno, R., Takala, J., Willatts, S., De Mendonça, A., Bruining, H., et al., 1996. The SOFA (Sepsis-related organ failure assessment) score to describe organ dysfunction/failure. On behalf of the working group on sepsis-related problems of the european society of intensive care medicine. Intensive Care Med., 707–710
Vincent, J.L., Rello, J., Marshall, J., Silva, E., Anzueto, A., Martin, C.D., et al., 2009. International study of the prevalence and outcomes of infection in intensive care units. JAMA 302 (December (21)), 2323–2329. American Medical Association.
Warren, D.K., Quadir, W.W., Hollenbeak, C.S., Elward, A.M., Cox, M.J., Fraser, V.J., 2006. Attributable cost of catheter-associated bloodstream infections among intensive care patients in a nonteaching hospital. Crit. Care Med. 34 (August (8)), 2084–2089.