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Antimicrobial efficacy of modern wound dressings: Oligodynamic bactericidal versus hydrophobic adsorption effect

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ABSTRACT

Locally infected wounds and wounds colonised with multidrug-resistant bacteria are commonly treated with local antimicrobial agents. Recently, wound dressings have been introduced into clinical practice that reduces bacteria by adsorbing bacteria on the dressing surface by a hydrophobic effect. Our aim was to investigate, whether this hydrophobic effect is only present in dressings coated with dialkyl carbamoyl chloride (DACC) or also in other modern wound dressings.

To determine the hydrophobicity of the dressing surface contact angle measurements were performed. In addition, for selected wound dressings, the bacteria eliminating effect of the wound dressings for Methicillin-resistant *Staphylococcus aureus* (MRSA) and *Pseudomonas aeruginosa* were measured.

31 of the 34 wound dressings presented with a hydrophobic surface. The reduction factor (RF) of one wound dressing without coating was 1.6 for MRSA and RF 2.1 for *P. aeruginosa*. One with a DACC coated dressing showed a RF of 0.7 (MRSA) and 1.2 (*P. aeruginosa*). The RF of a wound dressing that releases silver ions was 6.1 for MRSA and 7.5 for *P. aeruginosa* respectively.

The results show that both uncoated and with DACC coated wound dressings can have hydrophobic surfaces. These hydrophobic dressings are able to adsorb bacteria onto their surface and consequently remove them from the wound. However, the RF for wound dressings that release silver ions is significantly higher.

Depending on the degree of contamination, these results can have an effect on the clinical decision to choose certain products. We assume that for e.g. infected or critically colonised wounds, wound dressings with a hydrophobic effect may not be sufficient to significantly improve the microbiological wound condition. However, this assumption has to be verified in clinical studies.

1. Introduction

The bacterial load of a chronic wound can be a significant factor for delayed healing [1]. In addition, there is a relation between the concentration of the bacteria in the wound and the tendency of the wound to heal [2].

In modern wound management, wounds with localised signs of infection or a colonisation with multidrug-resistant organisms (MDRO) are considered as an indicator for a local antimicrobial therapy [3]. Active agents of choice are silver ions, polihexanide, octenidine and povidone-iodine [3]. Recently, there are new treatment options discussed using the hydrophobic effect that eliminates bacteria through adsorbing them into the wound dressing [4]. Wound dressings coated with dialkyl carbomyl chloride (DACC) are considered to have a strong bacteria-reducing effect. The reason for this effect is that the DACC-coating increases the hydrophobic characteristics of the dressing surface [5,6].

However, there are no studies available that show if this effect does only work for DACC-coated wound dressings or also for other modern wound dressings. Therefore, the aim of this study was to measure the hydrophobic surface properties of 34 representatively chosen wound dressings. In addition, we examined for selected wound dressings with and without a DACC coating on their ability to eliminate bacteria from agar surfaces in a quantitative in vitro model. In addition, a wound dressing that releases silver ions was included to evaluate if the hydrophobic effect can eliminate bacteria as effectively as the silver ions due to the oligodynamic effect [7,8].

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2. Material and methods

2.1. Determining of the hydrophobic surface

Contact angle measurement is a generally accepted method for determining the hydrophobic effect of aqueous solutions on surfaces [9]. If a surface shows a contact angle of around 90°, it is considered to have hydrophobic properties. To determine the contact angle, a drop of aqueous artificial wound exudate was placed [10] on the wound-facing side of the dressing. This drop was photographed with a Canon EOS 400D using a normal lens (18–55 mm) under standardised conditions (Fig. 1). The contact angle was measured on a printout with a geometry set square. A minimum of 3 and a maximum of 15 parallel measurements for each wound dressing were performed and the average value, median and standard deviation were calculated.

2.2. Determination antibacterial reduction factors

Agar plates were inoculated with 0.1 ml of a suspension containing the test bacteria, then the circular wound dressing specimen with a diameter of 20 mm were placed on top. After 24 h, the qualitative antimicrobial effect was determined by measuring the diameter of the zone of inhibition. To determine the quantitative antimicrobial effect, the agar directly under the test specimen (diameter 20 mm) was removed with an aqueous neutraliser solution and homogenised in a Stomacher bag. The neutraliser was validated in accordance with DIN EN 13727 [11]. From the homogenised suspension, the viable bacteria count was determined on Trypticase Soy bean Agar (TSA). In parallel a control study with cotton gauze soaked in water of standardised hardness (WSH [11]) was conducted in the same way as described above [7]. All trials were performed with 10 parallels. The reduction factors were calculated from the difference between the remaining bacteria count at the end of the control study and remaining count from the test series with the test specimen and calculated as $\log_{10}$:

$$\log 10\ \text{colony-forming units (CFU)/ml control study WSH} - \log 10\ \text{CFU/ml test specimen } 1 = \text{RF}.$$

Test wound dressings:

- Biatain Ag 10 cm × 10 cm, non-adhering foam dressing (Coloplast A/S, Humlebæk, Denmark, lot no. 2857610, expiry date May 2014).
- Biatain 10 cm × 10 cm, non-adhering foam dressing (Coloplast A/S, Humlebæk, Denmark, lot no. 2904925, expiry date August 2014).
- Alione 10 cm × 10 cm, hydro capillary wound dressing (Coloplast A/S, Humlebæk, Denmark, lot no. 3183838, expiry date February 2015).
- Cutimed Sorbact 10 cm × 10 cm bacteria-binding swabs (BSN medical GmbH, Hamburg, Germany lot no. 038093, expiry date October 2015).
- Cutimed Siltec Sorbact 12.5 cm × 12.5 cm bacteria-binding foam dressing with adhesive silicone edge and super-absorbents (BSN medical GmbH, Hamburg, Germany, lot no. 22810741, expiry date June 2015).
- Cotton gauze ES pads 10 cm × 10 cm (autoclaved, Paul Hartmann AG, Heidenheim, Germany, lot no. 61007601).

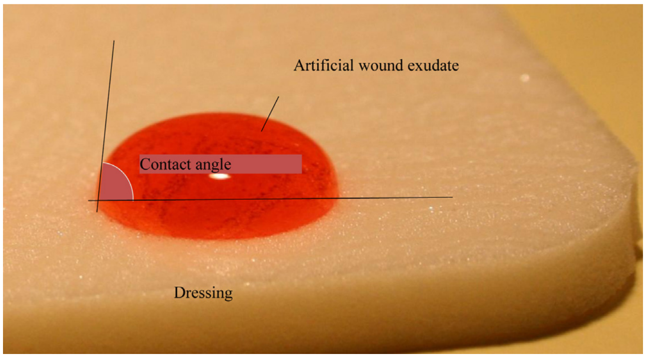

Fig. 1. The artificial wound exudate was applied with a pipette (1–2 ml) and directly under standardised conditions photographed.

Soaking liquid:	WSH (Dr. Brill + Partner GmbH, Hamburg)
Shape and size of the test specimen:	circular, diameter: 20 mm.
Storage conditions:	room temperature and darkness.
Culture mediums and organic load:	TSA without organic load.
Test temperature:	36 °C
Contact time:	24 h
Incubation temperatures:	36 °C ± 1 °C.
Neutralisation medium:	30 g/L polysorbate 80, 30 g/L saponine, 1 g/L histidine, 1 g/L cysteine (TSHC).
Test organisms:	Methicillin-resistant *Staphylococcus aureus* (MRSA) ATCC 33952 *Pseudomonas aeruginosa* ATCC 15442

3. Results

3.1. Hydrophobic effect

The contact angle was determined for 34 different wound dressings. An overview of the wound dressings and their main characteristics (category, coating and active ingredient) can be found in Table 1. With 120°, the greatest contact angle was measured for the Cutimed Sorbact gauze swab. The smallest contact angle, 71°, was measured for Atrauman AG (Table 1).

Due to similar structural characteristics, the tested wound dressings were grouped into eight different categories (Fig. 2):

- Polyurethane foam without active ingredients and without surface coating.
- Polyurethane foam with active ingredients and without surface coating.
- DACC without additional surface coating.
- Polyurethane foam without active ingredients but with silicone coating.
- Polyurethane foam with active ingredients and with silicone coating.
- DACC with additional surface coating.
- Polyurethane foam with DACC coating.
- Polyester-/polyamide fibre with coating and polyurethane foam with partial non-silicone adhesive layer.

All product categories have a contact angle of around 90°. With 111°, the group of wound dressings with DACC and additional

Table 1
Mean and median values and standard deviation oft he measured contact angles for all tested wound dressings.

Product	Manufacturer	Type of dressing	Mean	SD	Median	SD
Acticoat Moisture Control	Smith&Nephew GmbH	Polyurethan foam dressing	10.52	9.23	109	9.23
Allevyn Silver Non-Adhesive	Smith&Nephew GmbH	Polyurethan foam dressing	10.07	7.09	100	7.09
Allevyn Silber Schaumverband haftend	Smith&Nephew GmbH	Polyurethan foam dressing	94.8	1.71	94.5	1.71
Allevyn Silber Schaumverband nicht haftend	Smith&Nephew GmbH	Polyurethan foam dressing	89.4	4.03	89	4.03
Allevyn Ag Gentle	Smith&Nephew GmbH	foam dressing	92.9	3.28	94	3.28
Allevyn Ag Gentle Border	Smith&Nephew GmbH	foam dressing	99.4	10.70	96	10.70
AMD Antimicrobial Foam Dressing	Covidien Deutschland GmbH	foam dressing	80.7	3.08	81.5	3.08
Atrauman Ag	Paul Hartmann AG	Polyamide	71.2	6.62	72	6.62
Biatain Ag Haftend	Coloplast GmbH	Polyurethan-foam dressing	83.9	6.16	84.5	6.16
Biatain Ag nicht-haftend	Coloplast GmbH	Polyurethan-foam dressing	78.4	4.03	78	4.03
Biatain Nicht-Haftend	Coloplast GmbH	Polyurethan-foam dressing	85.3	8.22	86	8.22
Biatain Haftend	Coloplast GmbH	Polyurethan-foam dressing	88.3	4.68	87	4.68
Biatain Sanft-Haftend	Coloplast GmbH	Polyurethan-foam dressing	91.5	3.10	92	3.10
Biatain Silicone	Coloplast GmbH	Polyurethan foam dressing	95.9	9.33	94	9.33
Biatain Silicone Ag	Coloplast GmbH	Polyurethan-foam dressing	83.8	6.91	84.5	6.91
Biatain Silicone Lite	Coloplast GmbH	Polyurethan foam dressing	95.3	5.68	97	5.68
Cutimed Siltec Sorbact	BSN medical	foam dressing, DACC	100.6	12.64	106	12.64
Cutimed Siltec	BSN medical	foam dressing, DACC	91.8	8.52	90.5	8.52
Cutimed Sorbact Tupfer	BSN medical	Acetate, DACC	82.0	24.27	69	24.27
Cutimed Sorbact Tamponade	BSN medical	Acetate, DACC	120.3	7.91	120	7.91
Cutimed Sorbact Saugkompresse	BSN medical	Acetate, DACC	90.9	2.23	90	2.23
Cutimed Sorbact Hydroactive Gel-Wundauflage	BSN medical	Acetate, DACC	107.1	10.29	105	10.29
Cutimed Sorbact Hydroactive B Gel-Wundauflage mit Haftrand	BSN medical	Acetate, DACC	114.9	8.84	116	8.84
Cutimed Siltec L Silikon Schaumverband	BSN medical	foam dressing, DACC	96.9	3.54	97	3.54
DracoFoam PHMB	Dr. Ausbüttel & Co. GmbH	Polyurethan foam dressing	77.9	8.15	79	8.15
Mepilex Border	Mölnlycke Health Care GmbH	Polyurethan foam dressing	105.8	7.27	104.5	7.27
MepilexBorder Lite	Mölnlycke Health Care GmbH	Polyurethan foam dressing	100.3	12.47	101.5	12.47
Mepilex Border Ag	Mölnlycke Health Care GmbH	Polyurethan foam dressing	100.2	7.56	98	7.56
Mepilex Ag	Mölnlycke Health Care GmbH	Polyurethan foam dressing	115.7	11.76	116	11.76
Physiotulle Ag	Coloplast GmbH	Polyesterfiber	101	5.90	100	5.90
Urgotul AG Lite Border	Urgo Medical GmbH	Polyesterfiber	75.3	2.50	75.5	2.5
Urgocell AG Silver Border	Urgo Medical GmbH	Polyesterfiber/polyurethancompress	94.3	5.09	95	5.09
Urgocell Silver AG Plata NA	Urgo Medical GmbH	Polyesterfiber/polyurethancompress	96.4	5.89	95.5	5.89
Urgotul Silver AG Plata	Urgo Medical GmbH	Polyesterfiber	101.5	6.66	103	6.66

surface coating displays the largest contact angle. With 86°, the group of polyurethane foams without active ingredients and without surface coating displays the smallest contact angle (Fig. 2; Table 1).

3.2. Antimicrobial activity

In the qualitative agar diffusion test, only two of the five samples tested developed a zone of inhibition. With an average diameter of 0.4 mm for MRSA and 0.2 mm for *P. aeruginosa*, the zone of inhibition for Cutimed Siltec Sorbact was relatively small. Indeed, an inhibition was only measurable in 4 out of 10 parallel tests. The silver ions releasing wound dressing presented with a stronger inhibition effect. In average, the zones of inhibition measured were 2.1 mm (MRSA)/3.5 mm (*P. aeruginosa*). This effect was visible in all 10 parallel tests (Table 2).

The quantitative results for the antibacterial effect for Alione and Cutimed Sorbact similar log RF of approx. 0.5 for MRSA were

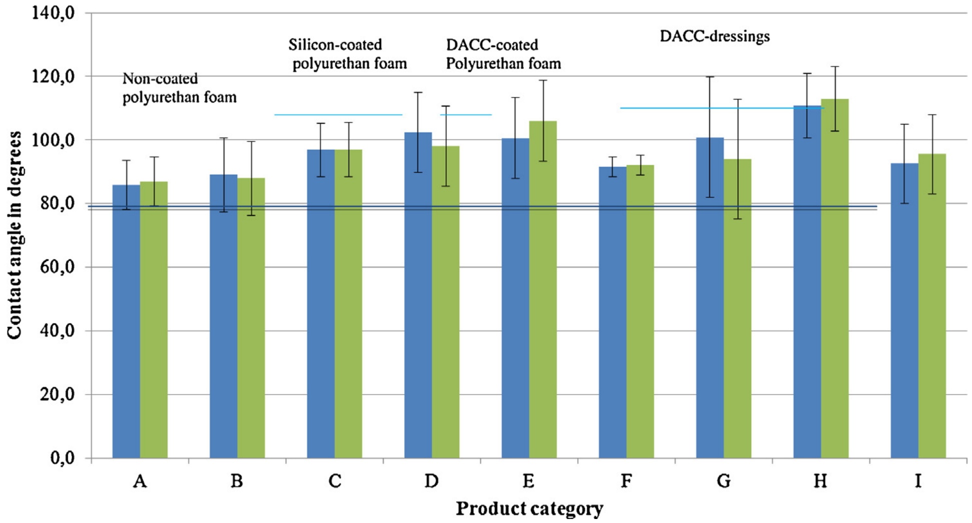

Fig. 2. Means (blue) and medians (green) of measured contact angles with artificial wound exudate in the different product categories. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 2
Means of inhibition zones in mm and standard deviation (SD) from qualitative agar diffusion assay for MRSA and *P. aeruginosa*.

	MRSA		*P. aeruginosa*	
	Mean	SD	Mean	SD
Biatain Ag	2.1	0.2	3.5	0.41
Biatain	0.0	0.0	0.0	0.00
Alione	0.0	0.0	0.0	0.00
Cutimed Sorbact	0.0	0.0	0.0	0.00
Cutimed Siltec Sorbact	0.4	0.5	0.2	0.27
Control (Gaze)	0.0	0.0	0.0	0.00

Table 3
Reduction factors (RF) from quantitative efficacy testing against MRSA and *P. aeruginosa*. Means of remaining colony forming units (cfu) and standard deviations (SD) are presented.

	MRSA			*P. aeruginosa*		
	Mean			$\log_{10}$ KBE		
	$\log_{10}$ cfu	SD	RF	$\log_{10}$ cfu	SD	RF
Biatain Ag	1.9	0.66	6.8	0.0	0.00	8.7
Biatain	7.1	0.33	1.6	6.6	0.27	2.1
Alione	8.4	0.40	0.4	8.1	0.55	0.6
Cutimed Sorbact	8.8	0.28	−0.1	8.8	0.37	−0.1
Cutimed Siltec Sorbact	8.0	0.25	0.7	7.5	0.69	1.2
Control (Gaze)	8.7	0.57	0.5	8.7	0.88	0.9

detected. For Biatain and Biatain Ag, significantly higher reduction factors of log RF 1.6/6.8 were detected. In the case of *P. aeruginosa*, comparable but higher RFs were measured (Fig. 3 and Table 3).

4. Discussion

The studies on the hydrophobicity of surfaces and on bacteria elimination delivered some remarkable and surprising results. The majority of the wound dressings tested presented a contact angle of around 90° and consequently have a hydrophobic surface. However, the differences between the individual product categories are statistically significant (*t*-test, significance level 5%, see Table 1). The measurement uncertainty of the study method, however, limits the statistical comparison. The drop of artificial wound exudate applied to the different wound dressings is absorbed with varying speed (initial absorption). However, the method requires a drop on the surface before every measurement (Fig. 1). Consequently, contact angle variations of below 10° do not qualify as an actual difference. The studies nonetheless confirm that a DACC coating makes the surface of wound dressings strongly hydrophobic [4–6]. However, the data also show that most other modern wound dressings also have a hydrophobic surface.

The results of the qualitative agar diffusion tests were as expected. Since only Biatain Ag releases an antimicrobial active ingredient as anticipated, a zone of inhibition only formed here [7]. The present results on quantitative bacteria elimination are, however, surprising. Our hypothesis was that the hydrophobic effect of the DACC-coated foam wound dressings would cause a quantitatively superior adsorption of bacteria compared to e.g. a "normal", uncoated standard polyurethane foam wound dressings. A maximum RF of 0.7 (MRSA) or 1.2 for *P. aeruginosa* were detected for the DACC-coated dressings. This confirms published data on the hydrophobic effect [5,6]. However, a higher RF of 1.6/log RF of 2.1 was detected for an uncoated polyurethane foam dressing.

This leads to the conclusion that there is no direct correlation between the hydrophobicity of wound dressings and bacteria elimination or adsorption. The uncoated polyurethane foam wound dressing with a contact angle of 88° absorbed more bacteria than the DACC-coated dressing with a contact angle of 111°. On the basis of these results, we can presume that in addition to the hydrophobic interactions of the bacteria with the surface, the exudate absorption capacity of the wound dressing and the size of the bacteria-adsorbing available surface area seem to playing an important role in passive bacteria elimination.

The test series on the silver-releasing wound dressing showed that, as expected, the active elimination of the bacteria with an antimicrobial active ingredient is significantly more efficient than the passive elimination [7]. This difference can be demonstrated very clearly when comparing the foam wound dressings Biatain and Biatain Ag. The only difference between these foam dressings is that Biatain Ag has been impregnated with silver ions. The additional effect of the silver ions can be calculated and is above 5 log steps (100,000×):

MRSA: 6.8 (RF Biatain Ag) – 1.6 (RF Biatain) = 5.2 ($\log_{10}$ difference)
P. aeruginosa: 8.7 (RF Biatain Ag) – 2.1 (RF Biatain) = 6.6 ($\log_{10}$ difference)

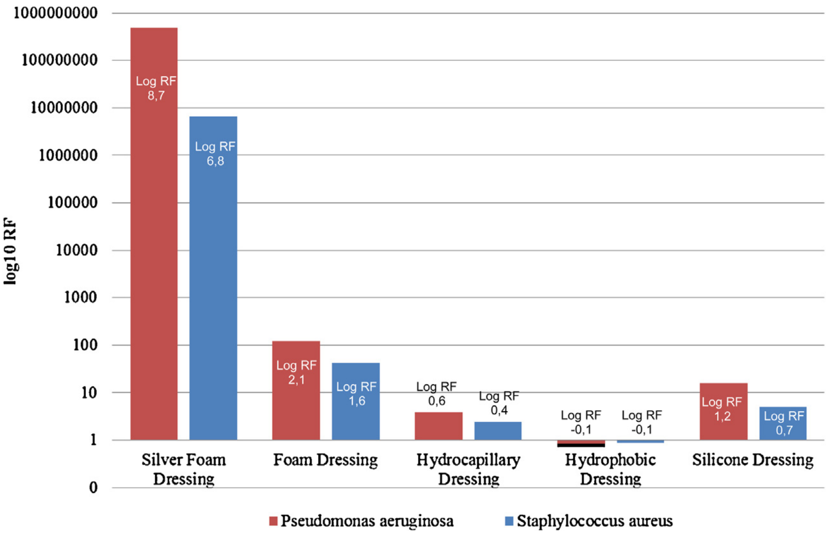

Fig. 3. Reduction factors (RF) of different wound dressings against MRSA and *P. aeruginosa*.

5. Conclusion

The results show that wound dressings coated with DACC and uncoated wound dressings can have a hydrophobic surface. These products are able to adsorb bacteria onto their surface and consequently eliminate them from the wound. However, the antimicrobial effect of wound dressings that release an active ingredient such as silver ions is significantly higher.

These lab results cannot be transferred directly to the clinical situation. However, they should be considered when choosing products to treat wounds with a high bacterial load. We assume that for e.g. infected or critically colonised wounds, wound dressings with a hydrophobic effect may not be enough to significantly improve the microbiological wound condition.

References

[1] Bowler PG, Duerden BI, Armstrong DG. Wound microbiology and associated approaches to wound management. Clin Microbiol Rev 2001;14(2):244–69.

[2] Davies CE, Hill KE, Newcombe RG, Stephens P, Wilson MJ, Harding KG, et al. A prospective study of the microbiology of chronic venous leg ulcers to reevaluate the clinical predictive value of tissue biopsies and swabs. Wound Repair Regen 2007;15:17–22.

[3] Kramer A, Daeschlein G, Kammerlander G, Andriessen A, Aspöck C, Bergemann R, et al. Konsensusempfehlung zur Auswahl von Wirkstoffen für die Wundantiseptik. ZfW; 2004.

[4] Butcher M. DACC antimicrobial technology: a new paradigm in bioburden management. MA Healthcare; 2011.

[5] Butcher M. Catch or kill? How DACC technology redefines antimicrobial management. MA Healthcare; 2011.

[6] Hallern B, Lang F. Has Cutisorb® Sorbact® proved its practical value as an antibacterial dressing? Medizin & Praxis »Infected Wounds. p. 1–7.

[7] Braunwarth H, Brill FHH, Brill H. Bacteriostatic and bactericidal in-vitro efficacy of antimicrobial wound dressings under organic load conditions. Wundmanagament 06/2012. p. 266–9.

[8] http://de.wikipedia.org/wiki/Oligodynamie.

[9] Teixera P, Azeredo J, Oliveira R, Chibowski E. Interfacial interactions between nitrifying bacteria and mineral carriers in aqueos media determined by contact-angle measurements and thin layer wicking. Colloids Surf. B: Biointerfaces 1998;12:69–75.

[10] Reitzel N, Marburger M, Torpe RM, Engell G. Ein in-vitro Testmodell zur Bestimmung des Absorptionsvermögens unter Druck von Schaumverbänden, Posterpräsentation auf dem 18. Lissabon: Kongress der EWMA; 2008.

[11] Anonymous. Chemical disinfectants and antiseptics – Quantitative suspension test for the evaluation of bactericidal activity in the medical area – Test method and requirements (phase 2, step 1); German version EN 13727:2012+A1:2013.