Which wound dressing is better for rapid absorption of wound exudate?

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Introduction

Wound exudate plays a crucial role in the healing process, but its management is pivotal as excessive amounts can impede recovery. Wound dressings, which are essential for moisture control and infection prevention, come in thousands of varieties, making the selection of appropriate care challenging. These dressings, varying in their ability to absorb moisture and control exudate, must be effectively matched with wound needs to optimize healing [1]. However, the scarcity of clinical trials and quantitative data on dressing efficacy poses significant challenges, highlighting the need for further research to enhance wound care solutions. Porous wound dressings are involved in multiple roles, including absorption, gelling, retention, and moisture regulation. Regardless of the mechanism, it is crucial to understand that interactions with exudate can significantly alter the wound-dressing interface. As an initial step, quasi-sessile/sessile droplet experiments are essential to investigate the physics of exudate interactions with commercially available dressings.

Extensive research has explored droplet impacts on solid surfaces [2], liquid layers [2], and moving films [3], but little has been done on droplet impact on complex porous surfaces like wound dressings, involving both spreading and penetration. To our knowledge, no previous experimental or numerical studies have examined quasi-sessile droplet interactions with actual wound dressings. However, a few related related studies on liquid droplet absorption into porous materials are highlighted below.

Wallace and Yoshida [4] were among the first to investigate droplet impact on permeable surfaces, focusing on the spread factor—defined as the ratio of the droplet's maximum spread diameter to its initial diameter—on water-sensitive paper, particularly in relation to impact energy for pesticide spray applications. Delbos et al. [5] conducted a preliminary study on droplet imbibition in a single pore of a porous surface. They found that at low impact velocities (< 1 m/s) and with smaller pore sizes, hydrophobic pores prevent penetration, while hydrophilic pores allow the droplet to be absorbed. At higher impact velocities and with larger pores, part of the droplet enters the capillary, forming a slug. More recently, Andredaki et al. [6] numerically modeled the absorption of a quasi-sessile droplet by a single cylindrical pore, examining the effects of pore size, liquid viscosity, and droplet diameter. They concluded that the pore size and liquid properties primarily govern the absorption dynamics, with droplet diameter having minimal influence. Most previous experimental studies have overlooked very low velocities and quasi-sessile droplets. Additionally, only a few numerical studies have examined the simultaneous spreading and penetration of sessile droplets on single pores, which fail to capture the full complexity of droplet dynamics in wound dressings. Therefore, this study aims to enhance wound management by uncovering the complex physics of exudate-dressing interactions.

Materials and methods

This study evaluates seven commercially available wound dressings, classified by their material into three groups: Polyester (Kerramax, Melonin, and Atrauman), Cellulose (Aquacel, Kerracel, and NA-Ultra), and Alginate-based (Kaltostat). Using a ZEISS LSM 800 Confocal Microscope, a 2-D stack images were obtained, which were analysed to obtain the 3-D topology of the wound dressing fibre and fibre diameter and pore diameter. We employ Simulated Body Fluid (SBF), which replicates the ionic composition of human plasma, to examine the interactions between the dressings and the fluid, crucial for understanding their performance in wound healing scenarios. The dynamic viscosity and surface tension of SBF at 20^0 C is 0.968 ± 0.018 mPas and 70.73 ± 1.59 mN/m, respectively. An photograph of the experimental test rig is shown in Fig. 1. High-resolution, temporal (20 KhZ), and spatial analyses of droplet dynamics and imbibition characteristics on these dressings were conducted using a high-speed camera linked to a microscope. The spatial resolution after calibration was found to be 10 µm/pixel. Droplets of 2.13 mm ±0.04 mm in diameter (D), were generated by directing air from a small syringe linked to a larger syringe via a pneumatic tube. This airflow caused a droplet to form at the tip of the hypodermic needle. Subsequently, the droplet detached and descended towards the test section due to gravity, with a pre-contact velocity (U) of about 0.025

mm/s. All the captured images were thoroughly analyzed in MATLAB to investigate the dynamics of the droplet-wound dressing interactions.

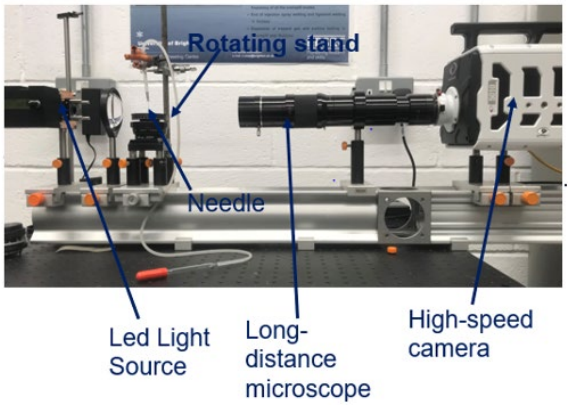


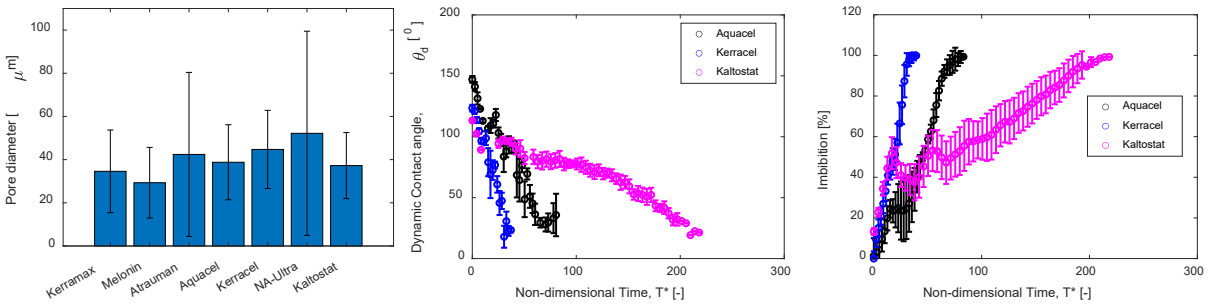
Figure 1. Experimental test rig showing the optical set-up.

Results and Discussion

Analyzing the images from the Confocal Microscope, it was observed that NA-Ultra has the largest pore diameter (see Fig. 2a), enhancing its potential for fluid absorption due to increased surface area. Additionally, NA-Ultra exhibited the largest fiber diameter (27 ± 4.5 µm), followed by Kaltostat (18 ± 3 µm), Kerramax (15 ± 3.5µm), and Melolin (10 ± 1µm). The fiber diameters of Melolin, Atrauman, Aquacel, and Kerracel were also found to be comparable within the margin of uncertainty.

Figure 1(b) shows the dynamic contact angle (θ_d) of three different wound dressings—Aquacel, Kerracel, and Kaltostat over non-dimensional time (T* = tD/U). At the beginning, all three dressings show a relatively high contact angle, suggesting they initially repel the fluid. This could be due to the intrinsic properties of the materials. Aquacel and Kerracel show a sharp decrease in contact angle early on. This indicates that the materials begin to absorb fluid more effectively as time progresses, reducing the contact angle as compared to Kaltostat.

Figure 1(c) depicts the penetration % of the droplet against T*. It can be observed that droplets penetrate faster in Kerracel as compared to Aquacel. This difference can be attributed to the higher porosity and pore diameter of Kerracel compared to Aquacel. The faster imbibition of cellulose-based dressing as compared to alginate-based dressing is because its glucose units are linked by glycosidic bonds with many hydroxyl (-OH) groups that form strong hydrogen bonds with water, enhancing its hydrophilicity. In contrast, alginate, a linear copolymer from seaweed with both hydroxyl and carboxylate groups, exhibits reduced hydrophilicity compared to cellulose.



(a) (b) (c)

Figure 2. (a) Pore diameter of various wound dressings (b) Dynamic contact angle against non-dimensional time for three different wound dressings (c) Imbibition against non-dimensional time for three different wound dressings.

Conclusion

The complete penetration of droplets into the wound dressing is driven by the combined effects of hydrodynamic focusing and capillary forces, improving the dressing's ability to manage wound exudate effectively. Moreover, cellulose-based dressings such as Kerracel and Aquacel absorb faster compared to alginate-based wound dressings (Kaltostat).

From a clinical point of view, wound dressings that quickly reduce contact angles are preferable for managing wounds with high exudate levels, swiftly drawing moisture away from the wound site. Specifically, cellulose-based dressings are recommended over alginate-based for their superior absorption capabilities in high-exudate scenarios. A parallel in-house study that has been conducted under the umbrella of the same research project and it was found that exudates behave as shear-thinning fluids, thus the droplet dynamics will be different as compared to the present study. Future research will incorporate shear-thinning fluids and conducting experiments in microchannels to explore exudate behaviour within pores.

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