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Does exudate viscosity effect the absorption rate of exudate into wound dressings?

Abstract

Objective

Exudate is a vital component of healing wounds and there are differences between acute exudate and chronic exudate, with the latter being described as highly toxic to the healing environment. Wound Exudate assessment is not easy for clinicians and attempts to standardise exudate quantification are emerging. It is highlighted here that the viscosity of wound fluid / exudate is equally as important as the quantity of fluid produced. Wound fluid viscosity increases when there is more protein present in it and as wound dressings exhibit various fluid handling mechanisms, it is important to understand how this interaction with the different exudate types, may alter the wound / dressing interface. This knowledge will ensure that a beneficial healing wound environment remains and not one which leaves harmful wound exudate on the wound surface. This study is designed to evaluate if the viscosity of exudate has an effect on the absorption time into 4 different families of wound dressings.

Method

This study evaluated the viscosities of two solutions and their effect on the absorption times of 4 different dressing types. The viscosities of the solutions were calculated using Oswald Viscometers then 2 ml of these solutions was applied to 4 different dressing types and repeated 10 times for each dressing as outlined in BS EN 13726-1:2002E¹. The parameters for temperature and frequency were also followed, and the absorption times recorded.

A 2 way repeated measures ANOVA was conducted to examine if exudate viscosity and dressing type, or their interaction had an effect on the absorption time.

Results

The results indicate that the Viscosity of the solution alone has a significant effect on the absorption time ($p < 0.01$) and that the combined effect of dressing type and viscosity had an effect on absorption, ($p < 0.01$).

The results also show that the type of dressing alone has a significant effect on the absorption time ($p < 0.01$).

When looking at the between subject effects of the dressings (4 different types) the only non-significant finding was between 2 dressings, the super absorbent and the Moderate (foam) absorbing dressing ($p = 0.097$). All other dressings had a between subject effect of ($p < 0.01$).

Conclusion

This study demonstrated that there is a significant difference in absorption times when investigating dressing types and viscosity of the test solution. The higher the viscosity of the fluid the longer it takes for the fluid to be absorbed into all dressing types tested. The results show that this delay is not simply determined by the dressing or by the viscosity of the fluid alone, but it is likely to be a combination of the mode of action of the dressing, pore size and particulate composition of the exudate which all require further investigation.

Key words: Wound fluid, Exudate viscosity, Dressing absorbency, Wounds, wettability.

Introduction

Exudate is a vital component of healing wounds. This plasma like substance occurs following injury to bathe the bodies' cells in vital nutrients and provide the molecules required for healing.² Exudate forms due to dilation and increased permeability of the blood capillaries, which allows electrolytes, nutrients, glucose, proteins, inflammatory mediators, matrix metalloproteinases (MMP's), growth factors and various white blood cells to enter the area and to decontaminate the injury site of injured body cells, bacteria and pathogens.^{3,4} The orchestration of exudate is carefully controlled to allow the correct amount to be produced and as the wound heals, the amount of exudate slowly reduces.⁵

Chronic wounds are described as 'wounds that fail to heal with standard therapy in an expected time frame' many are believed to be stuck in the inflammatory phase for one or more reasons.⁶ This may be due to trauma still occurring on the wound bed, low grade infection / colonisation, reduced vascular supply and associated comorbidities, to name a few. There are reported differences between acute exudate, the fluid that is produced in a newly occurring wound, and chronic exudate, the fluid that is produced in wounds that have been present for a prolonged period of time. Chronic wounds are described as highly toxic to the healing environment.⁷ Some of these differences are reported to be increased volumes of exudate, increased MMP's, reduced tissue inhibitors of MMP's (TIMPS), increased microbiome (biofilm / contamination level) and increased protein content.^{5,7} The viscosity of wound fluid increases when there is more protein present in the solution.⁸ This protein can be produced by prolonged vasodilation, (leading to increased vessel

permeability) the presence of bacteria/ infection,^{5,9} biofilms production of extra polymeric substance,⁴ and / or the deterioration of the wound bed, e.g. Fibrinolysis due to prolonged exposure to MMPs.⁷ As fluid complexity is increased, by the inclusion of more particulates, fluids take on more complex behaviour and can start to show a non-Newtonian response. It is this change in fluid dynamics which is believed to have an effect on the interaction between the dressing and the fluid and is under investigation within this study.

In a chronic wound, poorly managed exudate can lead to increased wound size, excoriation, pain and odour.^{5,7,9,-13} It is important to understand the differences in the different types of exudate as acute wound fluid assists in the ordered progression of wound healing, but chronic exudate is harmful, causing wound enlargement¹⁴ and can delay wound healing if not carefully managed.^{6,15,16} Exudate has many forms and can be described according to its presenting characteristics with Cutting³ reporting that there are 8 types of exudate.

Wound exudate assessment is not always easy. There are few validated tools to enable the practitioner to quantify what is present, and descriptions of exudate typically rely on the experience of the clinician and therefore the results could be subjective.^{8,17} There have been attempts to standardise exudate quantification,¹⁶ but this method only accounts for the volume of exudate produced and does not allow any descriptors of the exudate viscosity to be considered. It is becoming increasingly evident that the viscosity of wound fluid is equally important as the quantity of fluid produced.^{5,18,19} Grey et al¹⁹ have produced the wound exudate continuum, which now allows the clinician to grade the quantity of exudate and the viscosity of the exudate using a structured and quantifiable format.

Dressings are designed to absorb exudate in different ways.^{4,8,9} Today's market offers more than 2,000 topical wound care products,²⁰ with dressings being the main option for clinicians to manage exudate levels.^{14,21} Wound dressings exhibit various fluid handling mechanisms: absorption, gelling, retention and moisture vapour transmission.^{4,14,21} Whatever the mode of action of the dressing, it is important to understand how this interaction with the exudate, may alter the wound / dressing interface and ensure that a beneficial healing wound environment remains. Clinicians must be mindful that dressings that handle high volumes of low viscosity exudate may not deal as effectively with high volumes of high-viscosity exudate.²² If the selected dressing does not perform in the expected manner with exudate of a higher viscosity, this will result in the highly corrosive chronic exudate remaining on the wound bed and potentially causing the wound to deteriorate, rather than being absorbed into the dressing and allowing the wound to progress towards healing.

When dressings are tested for their absorption capabilities prior to release on the market, they are typically tested against what is deemed as 'normal' exudate as outlined in the British Standard Institution document, BS EN 13726-1.¹ According to Cutting³ normal is used to describe only 25% (2 of the 8 exudate types reported) of the different types of exudates that these dressings are potentially going to be used upon. In wounds that

become infected, exudate levels often increase and become viscous. This has been supported by a study by Jones and Barraud, who evaluated Kerramax care in managing heavily exuding wounds.²³ They reported that 59.5% of the wounds assessed had serous exudate and 40.5% had 'yellow and thicker' exudate.

To date few studies have explored how exudate viscosity may affect the performance of dressings used in routine practice. The vast majority are comparative studies investigating how dressings affect healing rate performance in different wound types.²⁴ Therefore the aim of this study is to determine if exudate viscosity has an effect on the absorption time into 4 different families of dressings.

Methods

This study was comprised of 2 parts.

Part 1: Preparation of test solutions

The first phase of this work was designed to standardise the preparation of the test solution viscosities. The first solution was produced using the procedure outlined in British Standard Documentation: Test methods for primary Wound dressings – Part 1: Aspects of Absorbency. (BS EN 13726-1:2002)¹. It was prepared by dissolving 8.298g sodium chloride and 0.368g of calcium chloride dihydrate in deionised water and making up to 1 litre in a volumetric flask. This solution, (solution 1), was considered the control and is a representation of plasma. This is the recommended test solution that all manufacturers test their dressing performance against prior to release on the market.

The second solution, (solution 2), was constructed by using 250 ml of Solution 1 which was then thickened with 1.4g of "Resource Thicken Up" to represent exudate of increased viscosity. Both Solutions had 3 ml blue Food dye added to each solution to aid identification of absorption during part 2 of the study.

The viscosity value of each solution was then calculated using Ostwald U tube Viscometer. This allowed the Kinematic viscosity of the liquids to be calculated from the observed time of flow, t seconds, by the formula:

V (viscosity in mm^2/s) = Ct Where C = viscometer constant and t = flow time

Solution 1 (artificial plasma solution) Kinematic Viscosity was calculated to be $0.975 \text{ mm}^2/\text{s}$ using Ostwald U tube Viscometer A.

Solution 2 (Increased viscosity plasma solution) Kinematic Viscosity was calculated to be $2.92 \text{ mm}^2/\text{s}$ using the Ostwald U tube Viscometer B.

Part 2

The absorbency of the four different dressings were tested with the 2 solutions described in part 1. The dressings were selected via convenience sampling from the local NHS trust dressing formulary. These consisted of 1 dressing from each of the dressing families: A Low absorbent, a medium absorbent (foam), a high and a super absorbent.

The rate of fluid absorption was tested by placing each dressing in a petri dish. 2ml of each test solution, warmed to 37°C, was dropped centrally from a pipette, suspended 1cm above the dressing by a clamp. The dressings were housed in an Orbital Incubator (Stuart S150) set to 37°C. The time taken for the solution to be fully absorbed into the dressing was recorded in seconds. This being defined as when no visible beads of solution fluid remained on the contact surface of the dressing. The time frame for testing was 30 minutes for each test solution. If the solution was not absorbed at the 30 minute cut of time a value of 1800 seconds was recorded to allow for calculations. The parameters were obtained from British Standards EN 13726-1:2002E Test methods for primary wound dressings, which also stated that the test is to be repeated 10 times for each of the dressing types. This was performed for all dressing types with both solutions.

Ethical application was not required for this study as it was performed in a laboratory and was not based on biological samples. The experiment was performed using simulated body fluid (BSF) the composition of which was outlined in BS EN 13726-1:2002E. ¹

A 2 way repeated measures Analysis of Variance (ANOVA) was performed using IBM SPSS Data analysis software, version 25, to investigate if the two independent variables, the dressing type or the solution viscosity, or their interaction are statistically significant.

Results

A 2 way analysis of variance was used to test the exudate absorption time against 2 different exudate viscosities and 4 different families of wound dressing.

With Solution 1, thin, the low absorbent dressing showed the fastest absorption time with a mean of 1.60 second, the high absorbent as the second fastest, (2.24 seconds), Super absorbent with 3.01sec and the moderate absorbent with a mean of 13.84 seconds. With Solution 2, the thicker solution, there appeared to be a reversing of the findings, with the moderate absorbent having the fastest average absorption of 70.4 seconds and the low absorbent being the slowest.

Table 1: Average times taken for the different fluids to be absorbed into the different families of dressings.

Table 1

	Low Absorbent	Moderate Absorbent	High Absorbent	Super Absorbent

Solution Type	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
%of dressings absorbing all solution in 30mins	100	50	100	100	100	100	100	100
Mean absorption time (seconds)	1.60	1687.2	13.84	70.4	2.24	855.3	3.01	254.8
Range of absorption times (seconds)	1.3 - 2.15	1235 – 1800	9.81 - 16.66	57 - 94	1.77 - 3.33	713- 1064	2.06 - 4.53	45 - 1386
St dev	0.26	1687.1	2.2	12.1	0.45	124.2	0.7	405.7

Table 2 shows the between subjects effects after performing the 2 way ANOVA of variance, with the dependent variable being the time taken for the fluid to absorb. Simple main effects analysis showed that dressing type had a significant effect on absorption rate of the solutions used ($p < 0.001$) They also showed that the viscosity of the solution had a significant effect on the absorption rate of the solutions used. ($p < 0.001$) It is also evident that when investigating the combined effect of both the dressing and the solution viscosity these 2 components together have a significant effect on the absorption rate. ($p < 0.001$).

Table 2.

Source	F Value	Significance (P Value)
Dressing	98.475	.001
Viscosity	380.039	.001
Dressing*Viscosity	100.595	.001

Table 3: shows the Pairwise comparison of the dressings used after performing the 2 way ANOVA of Variance. This shows that there is a significant difference between all of the dressing types used, $p < 0.001$, except for the moderate and super absorbent dressings, where $p = 0.097$ ($p > 0.05$).

Table 3.

Pairwise Comparisons Dependent Variable: Time taken to absorb.			
Dressing Used	Dressing Used	Std. Error	Significance P value
Low Absorbent	Moderate	51.631	< 0.001
	High	51.631	< 0.001
	Super	51.631	< 0.001
Moderate	High	51.631	< 0.001
	Super	51.631	0.097
High	Super	51.631	< 0.001

Discussion

Viscosity is an important property of fluids and describes a liquids resistance to flow and is related to the internal friction of the particles within the fluid.²⁵ As mentioned earlier, as fluid complexity increases, fluids take on more complex behaviour and start to show a non-Newtonian response. If a non-Newtonian fluid is placed under force they can change into either more solid or more liquid form, whereas a Newtonian fluid will remain the same. As is reported by Cutting, haemopurulent and purulent exudates contain more particulates and therefore have increased viscosity.³ A highly viscous solution has a high resistance to flow and it is hypothesised here that these thicker infected wound fluids would take a longer time to be absorbed into the dressings under investigation. This hypothesis was supported by the findings illustrated in table 2, which highlight that the thicker exudate, Solution 2, did take longer to be absorbed into all dressings having a p value < 0.01 .

The test solution 1, was constructed following the guidelines provided in the BS EN 13726-1:2002E document ¹, to create a repeatable artificial plasma substitute. This was found to have a kinematic viscosity value of 0.975 mm²/s and a calculated dynamic viscosity of 0.979 millipascal per second (mPa.s.) This value is slightly under the range reported by Kesmarky, Kenyeres, Rabai and Koth, who state the normal value range for actual plasma as being 1.10-1.30. mPa.s, at 37 degrees C.²⁶ This result would be expected to be slightly higher due to actual plasma containing more solutes than the artificial plasma constructed here. This is further supported by the Anton Parr conversion tables for whole blood.²⁷ They state the difference between kinematic viscosity and dynamic viscosity for whole blood at 37 degrees C is 2.78 mPa s and 2.65 mm²/s respectively.

The literature search for viscosity values of infected wound exudates did not provide any comparable values. To enable the readers some form of comparison in relation to the viscosities of the thicker solution used in the study, solution 2 was measured to have a viscosity value of 2.92 mm²/s. This places this thicker solution in the value range for the viscosity of milk.²⁸ As the literature regularly describes the consistency of infected wound fluid as thick and creamy,⁹ and those dealing with wounds regularly will recognise that fibrinous exudate has a similar consistency as milk and has a thinner viscosity than purulent exudate from infected wounds. Therefore, the author deemed that the value obtained for solution 2 was a suitable conservative consistency and a suitable substitute, for a thicker solution. Therefore, in the absence of true viscosity values for the 6 exudates described outside of 'normal', ³ this thickened test solution was deemed appropriate for the purposes of this study.

Dressing Mode of Action

The results of the statistical analysis show that the type of dressing, when considered alone (ignoring the solution viscosity) has a significant effect on absorption time, $p < 0.01$. All dressings require key performance characteristics to aid in wound healing. They must absorb and retain exudate, keep harmful chronic wound exudate away from the skin, perform effectively when under compression, be cost effective and easy to remove.⁴ Wound dressings are designed to have different fluid handling mechanisms: absorption, retention, gelling and moisture vapour transmission.

In all dressings, exudate is absorbed into the dressing matrix, and in the case of foam dressings, this is a reversible mechanism: the fluid can be released under pressure.⁴ some dressings shrink or expand when they come into contact with moisture,^{8,29} and others absorb and retain exudate vertically and are aided by moisture vapour transmission rate (MVTR)^{4,9,21}. and some dressing materials trap bacteria and exudate components (such as proteolytic enzymes), in vitro, so as to be beneficial to wound healing.³⁰ Due to these differing modes of action they can all produce different results when considering absorption of fluids of differing viscosities. It could be argued that these different dressings should not be evaluated together, however, the current British Standard document for dressing

absorbency¹ evaluate all dressings using the same method, therefore it was deemed appropriate to evaluate the different dressing types here.

The results in Table 2 show that the absorption rates of dressings are dependent on the exudate viscosity and the type of dressing used. It can be seen that the significance for the dressings is equal ($p < 0.001$), suggesting that the dressing used can have a significant effect on the absorption time of the exudate solution. It is also evident that when investigating the combined effect of both the dressing and the solution viscosity the significance is found to be $p < 0.001$, suggesting that the combined effect of the dressing type and the solution viscosity also has an effect on the absorption time into the dressing. So although the majority of the dressings investigated managed to absorb the test solutions in the 30 minute period, there were significant differences depending on the dressing type and solution used. This finding is supported by Persin et al³¹, who investigated absorption characteristics for saline, exudate and blood solutions. They found that liquid uptake in treated and un treated viscose non-woven dressings was faster in the saline and synthetic exudate samples when compared to the more viscous blood solutions. The clinical significance of these results is that not all dressings behave as expected when in contact with higher viscosity solutions, there is a significant difference between their absorption times, being slower to absorb, this may have an effect on the capacity of the dressings to perform appropriately in infected wounds and their ability to remove the more viscous wound exudate and leave it in contact with the wound bed for longer, potentially causing wound deterioration. This is highlighted in the standard deviations observed in Table 1. Where the low and super absorbent dressings both have a large variance in absorption time when presented with solution 2, the thicker exudate. This variance in performance is what could potentially cause exudate management issues with dressing performance when using these on infected wounds, or on wounds with more viscous exudates.

In another study by Terrill et al, they evaluated blood absorption in a selection of 12 fibre dressings (alginates and hydrofibres) and 15 Foam dressings. They found all fibre dressings absorb in under 18 seconds with Aquacel, (high absorbent dressing), taking 13 seconds, being the 3rd slowest absorber of the dressings tested. They also found that Biatain, (moderate absorbent dressing), took 30 seconds to absorb their test solution and was their 4th fastest absorber of the 15 foam dressings tested.³² Both of these are faster than the results obtained in this study and may be linked to the viscosity of blood differing from the composite of the artificial thick plasma solution used here. The design of the study was comparable, as the same fluid temperature was used, in an incubator for 30 minutes, however the quantity of liquid differed. They reported that if absorbency is slow, leakage out of the side of the dressing is possible under compression. This was a problem reported in 64% of weekly wound dressing assessments in a Randomised control trial looking into the effectiveness of two foam dressings in leg ulceration patients,³³ and could be contributed to the exudate viscosity and the dressings used in the study. Another lab based study investigating the physical characteristics of various dressings, by Thomas et al, found the

CMC hydrofibre to be the intermediate performing dressing of the 3 alginate / hydrofibre dressings tested, when looking at absorbency.³⁴ Unlike this study, they were evaluating the total absorption capacity of the dressings not the speed of absorption. Both of these studies highlight that different dressings perform with exudates slightly differently and adds weight to the need to repeat this study with different exudate viscosity values on a larger number of commercially available dressings. It also highlights the requirement for modification of the current British Standard documentation¹, to ensure that all dressings are evaluated against a wider variety of wound fluid viscosities to ascertain their true performance characteristics.

The results in table 3 show that there is a significant difference between all of the dressing types used, ($p < 0.001$), except for the moderate and Super absorbent dressings, where $p = 0.097$ ($p > 0.05$). These 2 dressings were the slowest of the 4 to absorb Solution 1 (thinner solution) and they were both the fastest to absorb Solution 2. (thick solution) This indicates that the composition of some dressings is more favourable to handling thicker viscosities than others.

When considering absorption times and the viscosities of the solutions, the thin viscosity solution was absorbed into the low absorbent dressing the fastest, and slowest into the moderate dressing, where beading on the surface of the dressing was observed. When considering the thicker exudate solution, the moderate dressing had the fastest absorption time with the low absorbent dressing being the slowest, with 50% of the samples having not been absorbed at the 30 minute cut of point in the study. This led to the large standard deviation observed in table 1 of the results section as those samples that had not been absorbed at 30 minutes were entered into the data calculations as having a value of 1800 seconds, however the actual value would have been larger. It was observed that when the test solutions were deposited on the dressings in question, some formed beads of fluid on the dressing surface more than others. This beading of fluids on the surface of a material is referred to as wetting or wettability.^{35,36} It was observed, that both the moderate and the super absorbent dressing both had a tendency to form droplets on the surface of the dressing for a while before the liquid was absorbed into the dressing, suggesting that these two dressings have low wettability, with the low and high absorbent dressing having higher contact wettability, at 37 °C. In order to improve the evaluation of dressing performance it would be advisable to record the contact angle of the droplets and establish the wettability of each product tested. The dressings, in question, had a variety of pore sizes. This is due to the manufacture process and the materials used being different between each product. It is hypothesised that the overall absorption ability of the dressings investigated appears to relate to a combination of factors including the wettability of the dressing in question, capillary action and fluid viscosity. Two of these elements were outside of the remit of this paper and the author intends to investigate them further in subsequent papers.

Recommendations for future research.

The results of this study indicate that there is a statistically significant difference in the time taken to absorb fluids of differing viscosities. It appears that the composition of some dressings is more favourable to the more viscous exudates and vice versa. Therefore, it is recommended that further in-depth investigations be performed into the construct of different dressings and also into the actual viscosities of wound exudates. This will enable a greater understanding of the interaction between these two substances and improve the clinical knowledge into more appropriate dressing selection.

It is recognised that the sample size of the dressings tested are insufficient to extrapolate the findings over all dressings on the market, but it would be recommended to repeat this evaluation with a larger selection of dressings to establish their true fluid handling characteristics with different exudate viscosities. The Author also recommends that these dressings and fluids of different viscosities be tested over a variety of different temperature settings as wound exudates do not remain at a constant 37° C.³⁷⁻⁴⁰.

Limitations of Study

It is acknowledged that the composition of the exudates used are not real exudate values as these are not currently known for the different ulceration exudate types. It is recommended that there are further studies into the molecular composite and viscosity values of ulceration fluid exudates. This will allow repeat testing and evaluation of more dressings from each of the dressing families with actual wound fluid viscosity values and provide an indication of their true performance in different clinical situations.

It is also acknowledged that the time restriction of 30 minutes could be considered a limitation of the study and the author would recommend that the data collection period be extended.

Conclusion

This study demonstrates that there is a significant difference in absorption times when investigating different dressing types with test solutions of different viscosities. The higher the viscosity of the fluid the longer it takes for the fluid to be absorbed into all dressing types tested. The results show that this significance is not as simple as being determined by the dressing alone, but it is likely to be a combination of the mode of action of the dressing, pore size and particulate composition of the exudate which all require further investigation. This study also highlights the potential requirement for a modification of the current British Standard documentation: Aspects of Absorbency,¹ to ensure that all dressings are evaluated against a wider variety of wound fluid viscosities to ascertain their true clinical performance characteristics.

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