Absorption Characteristics of Alginate Wound Dressings

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ABSTRACT: This study describes an investigation on the absorption characteristics of alginate wound dressings. The fluid that is absorbed by the dressing is divided into that which is held inside the fiber in the fiber structure and that which is held between the fibers in the textile structure. A number of dressings with different fiber structure and textile structure were studied and their effects on the absorption characteristics of the dressings were analyzed. It was found that a significant part of the absorption took place inside the fiber structure, in addition to the liquid held between fibers in the textile structure. High M alginate and high G calcium/sodium alginate fibers absorbed more fluid into the fiber than high G calcium alginate fiber, resulting in a better gelling ability. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 91: 953–957, 2004

Key words: fibers; biomaterials; adsorption; gelation; alginate

INTRODUCTION

Alginate is a natural polysaccharide composed of two types of monomer units, α-L-guluronic acid [G] and β-D-mannuronic acid [M] (Fig. 1). Alginate is traditionally known as a gelling and thickening agent and is widely used in the food and pharmaceutical industries for texture modifications and for drug deliveries, respectively.[1] Alginate fibers have been known for some time[2] for their ability to dissolve in aqueous alkali solutions and their nonflammable properties, which were commercially used as draw threads in the production of socks and for upholstery products, respectively. In recent years, alginate fibers have become widely used in the production of wound dressing materials. The alginate fibers and dressings (normally a calcium salt) have ion-exchange properties whereby calcium ions are replaced by the sodium ions in the body fluid when the dressing is in contact with the wound. As a result of this ion-exchange process, part of the calcium ions in the fibers are replaced by the sodium ions. Because sodium alginate is water soluble, water is drawn into the fiber and a fibrous gel is formed as a result.[3–5]

Today alginate wound dressings have become one of the most versatile wound dressings. These dressings have unique gel-forming properties and high absorption capacities. It is now generally accepted that wounds heal better in moist conditions[5,6]; the ability to form a moist gel has given alginate dressings their unique characteristics. They are gaining widespread use in the management of exuding wounds such as pressure sores and leg ulcers.[7,8]

Several alginate wound dressings are now commercially available. The construction and properties of each type of dressing differ, and attempts have been made to characterize and differentiate each type.[3] Our study investigated the absorption mechanism of alginate dressings to correlate the chemical/physical structures of the alginate fibers and the performance of each dressing.

EXPERIMENTAL

Materials

Four commercially available alginate dressings were used. Sorbsan (Maersk Medical) is a calcium alginate dressing made from alginate with a high mannuronate content. Tegagel (3M) is made from the same type of fibers as Sorbsan but the fibers in Tegagel are hydroentangled to form a nonwoven dressing, whereas Sorbsan is made in a loose form by pressurizing the carded web with pressure rollers. Curasorb (Kendall Healthcare) is a calcium alginate with a high guluronate content, made by needle punching a nonwoven felt. Kaltostat (ConvaTec) is made with a similar type of alginate as Curasorb and is also a needled nonwoven felt, but in the Kaltostat fibers, the alginic acid is in a mixed form of calcium and sodium alginate, the sodium ions being introduced into the fibers during the production process to improve the absorbency and gel-forming ability of the dressing.

Laboratory-made dressings were also used in this study. These fibers were made by extruding a 6% w/w aqueous solution of sodium alginate into an aqueous bath containing 1.5% calcium chloride dihydrate. The resultant fibers were stretched in hot water before they were washed in water and dried by ace-

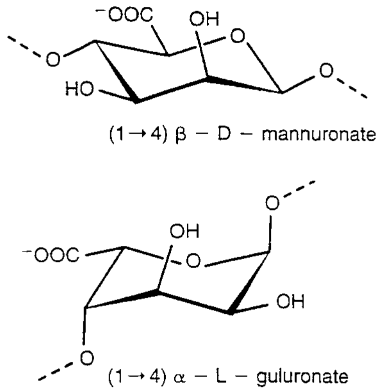

Figure 1 Chemical structure of guluronic acid (bottom) and mannuronic acid (top).

tone extraction to produce the fibers that were further processed into needle-punched felt and ropes through a textile carding process.

Several commercial non-alginate wound dressings were also evaluated. These include a knitted gauze made of viscose rayon continuous filament yarn (Smith & Nephew), a woven cotton gauze (ConvaTec), a nonwoven gauze made of cotton/polyester blend (Johnson & Johnson), and a polyester nonwoven felt (SSL International).

Analytical methods

Samples were cut to 5 × 5 cm sizes and conditioned at 25°C, 65% relative humidity overnight. The dressings were then weighed (W) before being placed in plastic petri dishes (90 mm in diameter) and wetted with 40 times their own weight of solution A (an aqueous solution containing 142 mmol of sodium chloride and 2.5 mmol of calcium chloride). The dish was then placed in a 37°C oven for 30 min. After that, the dressing was lifted out of the solution by holding with a forceps at one corner. The solution was allowed to drip for 30 s and the wet dressing was weighed (W_1). The sample was then placed in a centrifuge tube half filled with knitted gauze to contain the spin-off liquid. After centrifuging at 1200 rpm for 15 min, the dressing was taken out and weighed again (W_2). Finally, the dressing was dried to constant weight at 105°C for 4 h and the weight was recorded (W_3).

The fluid held within the dressing is divided into two parts: that which is held in the textile structure between the fibers and that which is held inside the individual fibers. In this experiment, $W_1 - W_2$ is the weight of fluid held between the fibers, whereas $W_2 - W_3$ is the weight of fluid held within the fibers. The ratios of $(W_1 - W_2)/W_3$ and $(W_2 - W_3)/W_3$ are calculated to convert the fluid absorption into gram fluid absorbed per gram of dry fiber, which can be used to compare different types of dressings. Results quoted in this study were the mean of five tests.

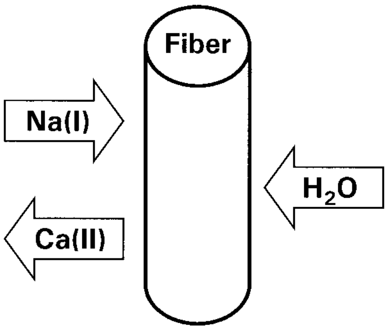

Figure 2 Ion exchange of calcium ions in the fiber and sodium ions in the contacting fluid.

RESULTS AND DISCUSSION

During the production process for alginate fibers, aqueous solutions of sodium alginate are extruded through fine holes into coagulation baths usually containing calcium chloride. Upon contact with calcium ions, the sodium alginate exchanges ions with calcium ions, and because the calcium ion is a divalent metal ion capable of forming water-insoluble calcium alginate, the alginate precipitates out in the form of a swollen gel. Upon further stretching, washing, and drying, calcium alginate fibers can be made.

On contact with wound exudates, a reverse process happens. As the calcium alginate fiber is in contact with fluid containing sodium ions, part of the calcium ions in the fiber exchanges with the sodium ions in the contacting fluid. Because sodium alginate is water

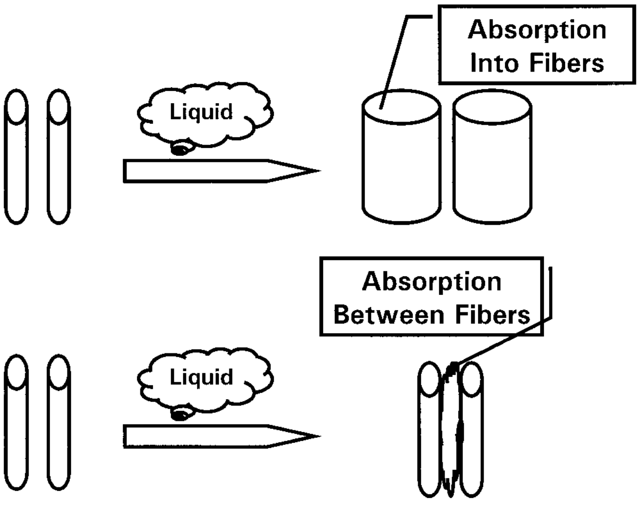

Figure 3 Illustration of the absorption of fluid by fibrous dressings.

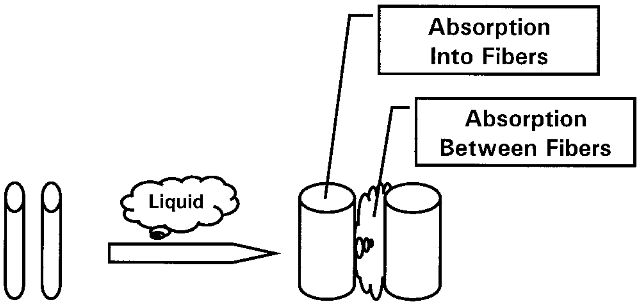

Figure 4 Illustration of the distribution of fluid absorbed between fibers and inside fiber.

soluble, water is drawn into the fiber and the fiber swells to form a gel (see Fig. 2).

When the fibers are made into a nonwoven felt, absorption of fluid by the dressing takes place in two forms. As Figure 3 shows, the fluid can be absorbed either into the fiber structure or between fibers in the textile structure. When the fiber is highly hydrophobic, such as glass fiber, any absorption of fluid would be held between fibers by capillary forces. On the other hand, in the case of some superabsorbent fibers, most absorption takes place inside the fiber. It is reasonable to suggest that in most cases, absorption occurs in both of these two places, as shown in Figure 4. By centrifuging the wet dressings, it is possible to separate the liquid held between the fibers ($W_1 - W_2$) from the wet fibers (W_2), and by drying the wet fibers, it is possible to further separate the fluid held inside the fiber ($W_2 - W_3$) from the fiber material itself (W_3).

In the case of a wound dressing, the fact that fluid can be absorbed into the fiber structure is important in several respects. First, when fluid is absorbed into the fibers, they swell as a result. As the fiber expands upon swelling, the free spaces between the fibers are closed, and any bacteria that are in the textile structure or in the wound exudates are then immobilized. This action limits wound infection and cross-infection in a hospital ward. Second, if the fluid is held between the fibers by capillary forces, it can easily migrate along the textile structure. Clinically, this would mean the spreading of wound exudates from the wounding area to surrounding healthy skin also covered by the dressing, causing maceration. Therefore, it is ideal that the dressing be capable of absorbing a large amount of exudates, and be able to contain the fluid within the fiber structure.[8]

Absorbency of the various types of wound dressings

$(W_1 - W)/W$ reflects the amount of fluid retained by the wound dressings on a gram per gram basis. This test is the standard absorbency test for alginate wound dressings.[9] As shown in Tables I and II, the various types of alginate dressings and other wound dressings have considerably different absorption capabilities. In the case of alginate wound dressings, the needle-punched nonwoven felt made of calcium/sodium alginate (Kaltostat) has the highest absorbency of about 16.3 g/g, whereas the hydro-entangled dressing made from high M calcium alginate fiber (Tegagel) has the lowest absorption capacity of about 4.8 g/g. The other two types of dressings, that is, the needle-punched high G felt (Curasorb) and the pressure-rolled unneedled high M felt (Sorbsan), have similar absorption capacities at about 12 g/g.

Alginate fibers can be made from different types of alginate having different guluronate and mannuronate contents, and the fibers can also be made into either calcium alginate or mixed salt fibers containing different proportions of calcium and sodium ions.[10–12] The nonwoven structure of the dressings can also be varied by adopting different nonwoven technologies, such as needle punching, pressure rolls, and hydro-entanglement. In general, the needle-punched felt has the highest level of porosity, whereas in the hydro-entangled felt, the individual fibers are heavily entangled and the pore structure is reduced. The absorption capacities increase with the increase in the porosity of the dressings and the increase in the sodium content of the fibers.

Table II shows the absorption capacities of a number of nonalginate dressings. Knitted gauze made of viscose rayon filament yarn had the lowest absorption at about 1.88 g/g, whereas the nonwoven polyester felt absorbs 18.3 g fluid per gram felt, the highest among all the dressings tested. For all the cellulosic type dressings (i.e., knitted viscose rayon gauze, woven cotton gauze, and nonwoven gauze), the absorption

TABLE I
Absorption Behavior of Commercial Alginate Felt Dressing

Product	$\frac{W_1 - W}{W}$	$\frac{W_1 - W_2}{W_3}$	$\frac{W_2 - W_3}{W_3}$	$\frac{W_1 - W_2}{W_2 - W_3}$	W_3
Sorbsan	11.98 ± 0.55	73.7 ± 2.11	15.2 ± 0.65	4.83 ± 0.25	0.139
Kaltostat	16.30 ± 0.63	47.1 ± 1.89	14.8 ± 0.71	3.18 ± 0.12	0.198
Curasorb	12.80 ± 0.53	32.0 ± 1.22	3.70 ± 0.13	8.62 ± 0.37	0.2245
Tegagel	4.80 ± 0.16	18.6 ± 0.81	10.6 ± 0.39	1.75 ± 0.11	0.270

TABLE II
Absorption Behavior of Non-alginate Products

Product	$\frac{W_1 - W}{W}$	$\frac{W_1 - W_2}{W_3}$	$\frac{W_2 - W_3}{W_3}$	$\frac{W_1 - W_2}{W_2 - W_3}$	W_3
Knitted gauze of viscose rayon filament yarn	1.88 ± 0.081	4.64 ± 0.23	2.72 ± 0.13	1.71 ± 0.10	0.379
Woven gauze	4.83 ± 0.21	11.5 ± 0.48	6.45 ± 0.29	1.78 ± 0.11	0.059
Nonwoven gauze	8.90 ± 0.34	24.0 ± 1.11	2.15 ± 0.11	11.04 ± 0.42	0.101
Nonwoven polyester	18.35 ± 0.81	67.6 ± 2.15	3.97 ± 0.16	17.01 ± 0.77	0.494

capacity increases with the increase in the porosity of the textile structure, in the order of knitted, woven, and nonwoven. Although alginate is a much more hydrophilic material than polyester, all the nonwoven alginate dressings tested in this study had a lower absorbency than that of the polyester nonwoven material. The hydrophobic nature of the polyester fibers might make them much more rigid when wet, which supports the porous structure of the dressing.

Fluid retention between fibers and inside fibers

By applying centrifugation to the wet dressings, the fluid that is retained between the fibers in the textile structure is separated from the original dressing structure. Further, the fluid that is retained inside the fibers can be measured by drying off the fluid from the fibers. By applying this technique, the mechanism of absorption behavior of the dressings can be studied to reveal the exact distribution of fluid retained by the textile structure and by the fiber itself.

Table I shows the absorption behavior of the various types of alginate dressings. It can be seen that for all the dressings, by far the majority of the fluid was held in the textile structure rather than in the fibers. However, the ratio of $(W_1 - W_2)/(W_2 - W_3)$ differs greatly for the different type of dressings, indicating that the distribution of fluid in the dressing varies for the different types of dressings. $(W_2 - W_3)/W_3$ reflects the amount of fluid held in the fiber per gram of dry fiber. The highest figure comes from the high M calcium alginate fiber, given that it exchanges ions readily and gels rapidly on contact with sodium-containing liquid. However, although Sorbsan and Tegagel were made with similar high M fibers, the Sorbsan fiber had a higher gel swelling ratio than that of the Tegagel fiber, indicating the effect of the nonwoven structure on the swelling of the fibers. It is also interesting to see the difference between Curasorb and Kaltostat. Although they are both made of high G type alginate, the Kaltostat fiber contains about 80% calcium alginate and 20% sodium alginate, whereas the Curasorb is mostly calcium alginate. Kaltostat takes about 14.8 g solution A inside the fiber per gram of dry fiber, whereas Curasorb absorbs only 3.7 g.

In terms of the distribution of fluid, Sorbsan has a $(W_1 - W_2)/(W_2 - W_3)$ ratio of 4.83, whereas that of Tegagel is 1.75. The loose textile structure facilitated Sorbsan's retention of fluid within the textile structure; thus its absorbency between fibers is 73.7 g per gram of dry fiber, whereas the corresponding value for Tegagel is only 18.6 g/g. Curasorb also has a much higher $(W_1 - W_2)/(W_2 - W_3)$ ratio than that of Kaltostat. Its rigid structure of high G calcium alginate made it less able to swell and less absorbing than the Kaltostat dressing.

Comparison of fluid absorption behavior between alginate felt and rope

Compared to the felt dressings, the alginate ropes are loosely assembled fibers with little fiber/fiber interaction. The main difference between the felt and rope is the accessibility of the individual fibers to the fluid, mainly because the ropes take a cylindrical form with the inner part of the rope farther away from the fluid than in the felt products. Table III shows the absorption behavior of Sorbsan ribbon and Kaltostat rope. In general, compared to those nonwoven dressings made of the same type of fibers, the differences in the various parameters are small.

TABLE III
Absorption Behavior of Alginate Ropes

Product	$\frac{W_1 - W}{W}$	$\frac{W_1 - W_2}{W_3}$	$\frac{W_2 - W_3}{W_3}$	$\frac{W_1 - W_2}{W_2 - W_3}$	W_3
Sorbsan ribbon	10.85 ± 0.51	52.5 ± 2.12	13.2 ± 0.61	3.97 ± 0.21	0.168
Kaltostat rope	11.46 ± 0.48	48.6 ± 1.65	15.6 ± 0.66	3.10 ± 0.14	0.157

TABLE IV
Comparison of Sterile and Unsterile Products[a]

Product	$\frac{W_1 - W}{W}$	$\frac{W_1 - W_2}{W_3}$	$\frac{W_2 - W_3}{W_3}$	$\frac{W_1 - W_2}{W_2 - W_3}$	W_3
Unsterilized alginate rope	19.52 ± 0.95	76.3 ± 2.41	23.7 ± 1.11	3.22 ± 0.14	0.249
Sterilized alginate rope	16.57 ± 0.58	75.3 ± 2.65	17.4 ± 0.67	4.32 ± 0.21	0.2205
Unsterilized alginate nonwoven dressing	20.85 ± 0.85	82.4 ± 2.98	24.3 ± 0.92	3.38 ± 0.14	0.243
Sterilized alginate nonwoven dressing	18.72 ± 0.82	82.6 ± 3.12	21.0 ± 0.87	3.93 ± 0.14	0.266

[a] The alginate fibers used in this experiment constitute a mixed calcium/sodium alginate containing about 70% calcium alginate and 30% sodium alginate.

Effect of sterilization on the absorption behavior of the alginate dressings

Table IV shows the absorption behavior for sterilized and unsterilized alginate nonwoven dressings and ropes. The sterilization is done by γ-irradiation at 25 kGy. Post-sterilization, there is a significant reduction in the $(W_2 - W_3)/W_3$ parameter, indicating that the sterilization process has either made the fibers more crystallized, or in some form crosslinked the alginate, which makes it less absorbent. Interestingly, in both the nonwoven dressing and rope, the absorption between fibers $(W_1 - W_2)$ remains largely unchanged before and after sterilization, which means that the sterilization process has little effect on the textile structure. Because the fibers absorb less after sterilization, the overall absorption capacities of the dressings show a reduction post-sterilization.

CONCLUSIONS

This study has shown that the absorption behavior of alginate wound dressings is affected by a number of factors. With alginate, a significant part of the absorption occurs inside the fiber structure, in addition to the liquid held between fibers in the textile structure. High M alginate and high G calcium/sodium alginate fibers absorb more fluid into the fiber than high G calcium alginate fiber, resulting in a better gelling ability. The textile structure also has a significant effect on the absorption behavior of alginate dressings, especially with regard to the liquid held between fibers. In general, needle-punched felt absorbs more than hydro-entangled fibers. The study on the effect of sterilization shows that γ-irradiation mainly affects the absorption within the fibers, but has little effect on the absorption between fibers.

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