The Characterization of Alginate Wound Dressings with Different Fiber and Textile Structures

Yimin Qin

The Biochemical Materials Research and Development Center, Jiaxing College, Jiaxing 314001, Zhejiang Province, People's Republic of China

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ABSTRACT: Seven commercially available alginate wound dressings with different polymer, fiber, and nonwoven structures were characterized in this study. The performances of these dressings were compared in terms of their absorbency capacities, gel swelling ratios in water and normal saline, wicking of fluid, and dry and wet strengths. Results show that the absorbency and swelling ratios were strongly affected by the guluronate and mannuronate contents of the alginate, the calcium and sodium contents of the fibers, and the nonwoven structures of the dressing. The different types of alginate wound dressings also had significantly different dry and wet strength. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 100: 2516–2520, 2006

Key words: alginate fiber; wound dressing; absorbency; gel swelling

INTRODUCTION

Alginate fibers were first described by Speakman and Chamberlain[1] in 1944 in a study of the wet-spinning process for alginate. Although these fibers were later used as draw threads for the production of socks and as home decoration materials, utilizing their ability to dissolve in dilute aqueous alkali solutions and their noninflammable properties, it was not until the 1980s when alginate fibers began widely used in the manufacture of wound dressings. In this particular field, the properties of alginate fibers are unparalleled in many respects. First, as a natural polymer, alginate is nontoxic and safe to use on wound surfaces and in cavities. Second, when the water insoluble calcium alginate is placed in contact with wound exudates, the calcium ions exchange with sodium ions in the body fluid and calcium ions are released, which can act as a hemostatic agent. Third, as calcium alginate slowly turns into sodium alginate, it absorbs a large quantity of exudates and turns itself into a gel, which helps keep a moist interface on the wound surface. Forth, as a natural polymer, alginate is a renewable resource with unlimited supply in nature.[2–7]

Since Sorbsan™ was first commercialized in 1981, there have been a large number of alginate wound dressings launched in the health care market, mainly for the treatment of wounds with a large amount of exudates. Today, there are more than 10 types of alginate wound dressings available on the British Drug Tariff alone.

Chemically, alginate is a polymeric acid composed of α-L-guluronic acid (G) and β-D-mannuronic acid (M) (see Fig. 1). Alginate extracted from different types of seaweed can differ significantly in their G and M contents and also in the GG and MM contents. It is known that alginate high in G and GG contents can form more rigid gels than those high in M and MM contents.[8]

Alginate fibers are made by extruding an aqueous solution of sodium alginate into an aqueous calcium chloride bath. During the production process, the production conditions can be altered to produce fibers with different amount of sodium and calcium contents. It is known that fibers containing a small proportion of sodium ions are more absorbent than the pure calcium alginate fibers.[9,10]

The alginate fibers can be converted into wound dressings by using a number of textile processes. Because of its simplicity and also the high absorbency of the product, nonwoven is the main form of alginate wound dressings. A number of nonwoven structures such as needling, pressure rolling, and hydroentanglement have been used for making alginate wound dressings.

In view of the diversified techniques that have been used for the production of alginate fibers and wound dressings, this study aims to characterize a number of commercially available alginate wound dressings to better understand the effect of fiber and textile structures on the performances of various types of alginate wound dressings.

EXPERIMENTAL

Seven types of commercially available alginate wound dressings were used in the present study. They were

Correspondence to: Y. Qin (yiminqin@hotmail.com).

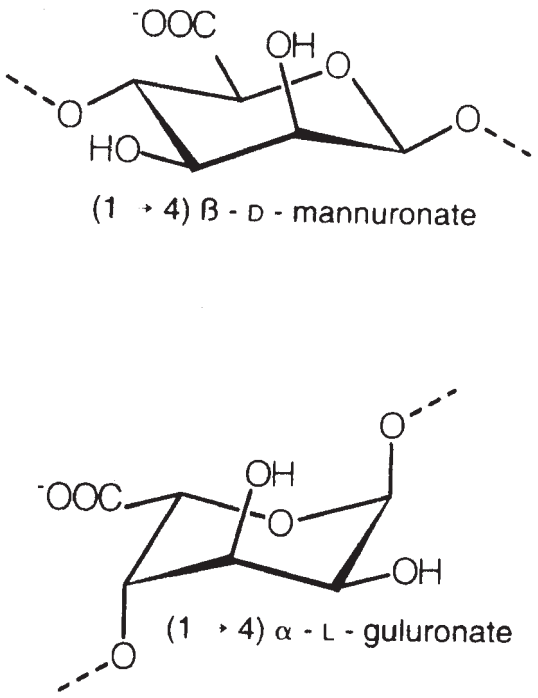

Figure 1 The chemical structures of α-L-guluronic acid and β-D-mannuronic acid.

Sorbsan from Maersk Medical (UK), Algosteril™ from Laboratory Brothier (France), Kaltostat™ from Convatec (UK), Urgosorb™ from Urgo (France), Tegagel™, and Tegagen HG™ from 3M (USA), and Curasorb™ from Kendall Healthcare (USA), respectively.

The fiber calcium and sodium contents were analyzed by using atomic absorption spectroscopy. Fibers were first digested in concentrated sulfuric acid before tests were carried out. The calcium and sodium contents are expressed as the percentage of carboxylic acid groups being in calcium salt or sodium salt. This assumes that all the carboxylic acid groups on the alginate exist either in calcium salt or in sodium salt. Assuming the w/w calcium content of the fiber is C_1 and the sodium content is C_2, the fiber calcium content equals to $[C_1/20]/[C_1/20 + C_2/23] \times 100\%$, while the fiber sodium content is $[C_2/23]/[C_1/20 + C_2/23] \times 100\%$ (note: one calcium ion binds with two carboxylic acid group).

The gel swelling abilities of the alginate fibers were measured by placing 0.2 g fiber in 100 mL of either distilled water or 0.9% (w/w) aqueous sodium chloride solution (normal saline). After one hour, the fibers were separated with the contacting solution and placed in a centrifuge tube with the bottom half filled with knitted viscose rayon fabric to contain the spin off solution. The centrifuge was carried out at 1200 rev/min for 15 min. After that, the fiber (W_1) was dried at 105°C to constant weight (W_2). The gel swelling ratio is expressed as the ratio between the weight of the wet sample and that of the dry sample, i.e., W_1/W_2.

The absorption capacities of the dressings were measured according to the method as specified in the British Pharmacopoeia monograph for alginate dressings and packings.[11] A piece of 5 cm × 5 cm dressing (W_1) was placed in a flat bottomed petri dish 90 cm in diameter, and to the dish was added a quantity of solution A 40 times the weight of the dressing. The British Pharmacopoeia specifies solution A as an aqueous solution containing 142 mmol of sodium chloride and 2.5 mmol of calcium chloride. After conditioning at 37°C for 30 min, the sample was lifted from one corner and held in the air for 30 s before the weight of the sample was measured (W_2). The absorption capacity is expressed as $(W_2 - W_1)/W_1$ (g/g).

The wet integrity test was carried out by placing a piece of 5 cm × 5 cm dressing in a wide-necked 250-mL conical flask. After adding 50 mL of solution A, the flask was swirled gently for 60 s. The dressing was considered wet dispersible if the fibers were separated to leave no evidence of the original structure. It was considered wet integral if there was clear evidence of the original structure.

The fiber diameters and swelling behavior were measured under an optical microscope. To assess the swelling behavior, the fibers were wetted with either distilled water or 0.9% saline; the magnification was 200.

The wicking behavior was tested on a gel blocking test kit, which was made of a semispheric plastic cup with a diameter of 50 mm and a depth of 5 mm. Five

TABLE I
Key Structural Features of Seven Commercially Available Alginate Wound Dressings

	Ratio between guluronate and mannuronate contents	Ratio between calcium and sodium content	Nonwoven structure
Sorbsan™	~39/61	~96.6/3.4	Unneedled
Tegagel™	~39/61	~96.6/3.4	Hydroentangled
Algosteril™	~68/32	~99.6/0.4	Needled
Kaltostat™	~68/32	~80/20	Needled
Tegagen HG™	~38/62	~65/35	Needled
Curasorb™	~68/32	~99.2/0.8	Needled
Urgosorb™ (alginate/CMC ratio ~85/15)	~68/32	~95.2/4.8	Needled

TABLE II
Performance Characteristics of Three Calcium Alginate Dressings

Product	Algosteril™	Curasorb™	Sorbsan™
Weight per unit area (g/m^2)	125.55 ± 8.15	127.50 ± 5.80	125.20 ± 6.50
Absorbency (g/g)	14.27 ± 0.41	14.77 ± 0.36	16.75 ± 0.27
Wet integrity	Integral	Integral	Dispersible
Gel swelling ratio in water	1.85 ± 0.13	2.12 ± 0.12	2.14 ± 0.14
Gel swelling ratio in saline	5.23 ± 0.42	4.42 ± 0.13	13.91 ± 0.77
Fiber diameter (μm)	25.25 ± 1.22	15.27 ± 1.68	17.4 ± 1.87

milliliter of 1.5% aqueous sodium citrate solution was first placed in the cup. A piece of 10 cm × 10 cm dressing was then placed on top of the solution. After 1 min, the dressing was lifted up and the largest diameter on the wet circle of the dressing was measured. Wicking is expressed as the ratio between this diameter and the diameter of the original cup.

The dry and wet strength of the alginate wound dressings were tested by cutting a strip of felt 2 cm in width from each direction of the felt. For the two directions, the strength for the weak direction was quoted. For the wet strength test, the felt was cut and then wetted with solution A similar to the absorbency test. After 30 min in a 37°C oven, the felt was lifted out of the solution and tested for breaking strength. The gauge length was 50 mm and the cross-head speed was 50 mm/min.

RESULTS AND DISCUSSION

There are three structural levels for a fibrous wound dressing, i.e., molecular, fibrous, and textile structures. Alginate is a copolymer and its molecules differ on the relative proportions of α-L-guluronic acid and β-D-mannuronic acid monomers. It is known that for alginate extracted from different species of brown seaweeds, the guluronate content can vary from 68% for those extracted from the stipes of Laminaria Hyperborea to 41% for those extracted from Laminaria Digitata.[12] Alginate high in guluronate content (high G) is capable of forming firmer structures with calcium ions and hence stronger gels than those high in mannuronate content (high M).[8]

During the wet spinning process, sodium alginate is converted into calcium alginate. In some cases, part of the alginic acid in the fiber can form salt with sodium ions, resulting in a mixture of calcium/sodium alginate.[13–16] The calcium ions are needed for the fiber to maintain an integral structure during production, while the sodium ions are introduced into the fibers to improve the absorbency of the fibers.

Table I outlines the key structural features for the seven types of commercial alginate wound dressings.

Effect of guluronate and mannuronate contents

Table II shows the analysis results for Algosteril, Curasorb, and Sorbsan dressings. All three dressings are made of calcium alginate fibers. Both Algosteril and Curasorb are made of high G alginate, while Sorbsan is made of high M alginate. The high G- and high M-type fibers differ significantly on the gel swelling ratio in saline. As can be seen in Table II, although the water swelling ratios were similar for the three alginate fibers, Sorbsan had a significantly higher saline swelling ratio than both Algosteril and Curasorb. This is understandable, as the calcium ions are bound more strongly with high G alginate, and hence, ion exchange with sodium ions in the solution is more difficult for high G alginate fiber. For high M fibers, the calcium ions in the fibers can be easily replaced by sodium ions in the solution, resulting in a better gelling ability.

As the fibers can swell better, the Sorbsan dressings can absorb more fluid than the Algosteril and Curasorb dressings under the same test conditions. Because they swell less, Algosteril and Curasorb have better wet integrity than Sorbsan.

Effect of calcium and sodium contents

As sodium alginate is water soluble, by making alginate fibers a mixture of calcium and sodium alginate, it is possible to improve the absorbency of the alginate dressings. Both Tegagen HG and Kaltostat are made of calcium and sodium alginates; the former is a high M alginate, while the later is made of high G alginate. Analysis results showed that the proportions of alginic acid as calcium and sodium salts were about 65/35 and 80/20, respectively, for Tegagen HG and Kaltostat, as compared to 96.6/3.4 and 99.6/0.4 for Sorbsan and Algosteril, respectively. As can be seen in Table III, both Tegagen HG and Kaltostat have signif-

TABLE III
Performance Characteristics of Calcium/Sodium Alginate Dressings

	Tegagen HG™	Kaltostat™
Fiber sodium content	~35%	~20%
Weight per unit area (g/m^2)	119.01 ± 15.11	120.5 ± 11.5
Absorbency (g/g)	20.51 ± 0.66	17.40 ± 0.35
Wet integrity	Dispersible	Not dispersible
Gel swelling ratio in water	37.67 ± 1.25	7.65 ± 0.35
Gel swelling ratio in saline	16.75 ± 0.85	5.79 ± 0.21
Fiber diameter (μm)	12.15 ± 0.65	16.3 ± 1.95

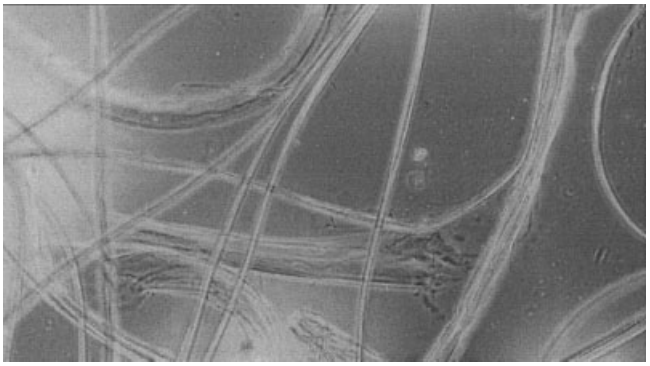

Figure 2 Swelling of Kaltostat™ fibers in water, 200×.

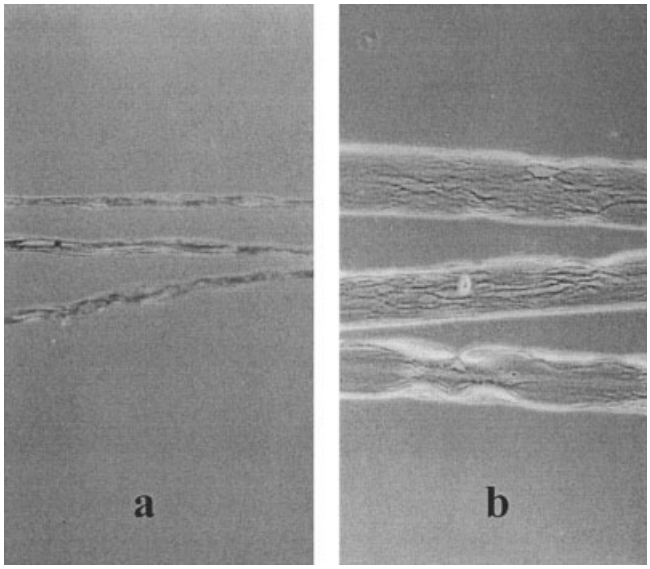

Figure 3 Swelling of Urgosorb™ (alginate/CMC) fibers, (a) dry and (b) in saline, 200×.

icantly higher water swelling ratios than Sorbsan and Algosteril, indicating the high water holding abilities of the sodium ions in the fibers. Because of the ion strength in the solution, the saline swelling ratios for Tegagen HG and Kaltostat were lower than the water swelling ratios; however, they were still much higher than the corresponding figures for Sorbsan and Algosteril.

Tegagen HG had an absorbency of 20.51 g/g, about 22% higher than Sorbsan under similar testing conditions. The absorbency of Kaltostat showed a similar level of improvement over Algosteril, although both fibers were made of similar high G alginate.

It is interesting to note that overall, the Kaltostat fibers contain about 20% sodium alginate, while under microscopic observation, it is clear that the sodium ions are not uniformly dispersed among the fibers. As shown in Figure 2, some fibers were clearly more swollen than other fibers, indicating the different levels of sodium ions within the different individual fibers. The Tegagen HG sample showed more uniform swelling.

Effect of nonwoven structures

The Tegagel and Sorbsan dressings are made of similar high M calcium alginate fibers. Test results showed that the absorbency for Tegagel is only 4.68 g/g compared to 16.75 g/g for Sorbsan. As Tegagel is made of a hydroentangled structure, the fibers in the dressing are closely compressed, and hence, it is more difficult for the fluid to diffuse into the nonwoven structure. On the other hand, Sorbsan is made of an unneedled pressure rolled structure; the swelling of the fibers is easy when wet.

Because the fibers are closely adhered to each other, the Tegagel sample showed a high degree of wet integrity.

Effect of adding carboxymethyl cellulose into alginate

Because both are water soluble polysaccharides, sodium alginate and carboxymethyl cellulose (CMC) can be mixed together in an aqueous solution and made into a composite fiber.[17] The CMC component disrupts the regular structures of alginate, and hence, it is more easy for the alginate/CMC fiber to swell in the presence of saline. As can be seen in Table IV, Urgosorb, which is an alginate/CMC composite fiber containing about 15% CMC, showed a significantly higher saline swelling ratio than both Algosteril and Curasorb, although the three samples are made of similar high G calcium alginate. The absorbency for Urgosorb is more than 30% higher than Algosteril and Curasorb under similar test conditions.

It is clear that by adding CMC into alginate, the performances of the alginate dressings can be improved in a similar way as when sodium ions are

TABLE IV
Comparison of Alginate/CMC to Other High G Alginate Dressings

	Urgosorb™	Algosteril™	Curasorb™	Kaltostat™
Absorbency (g/g)	20.35 ± 0.75	14.27 ± 0.41	14.77 ± 0.36	17.40 ± 0.35
Gel swelling ratio in water	4.25 ± 0.25	1.85 ± 0.13	2.12 ± 0.12	7.65 ± 0.35
Gel swelling ratio in saline	9.65 ± 1.42	5.23 ± 0.42	4.42 ± 0.13	5.79 ± 0.21

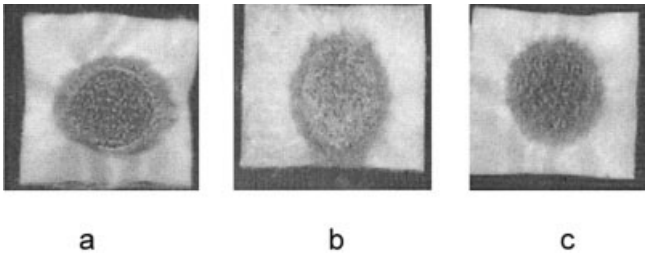

Figure 4 Wicking behavior for (a) Sorbsan™; (b) Kaltostat™; and (c) Urgosorb™.

introduced to the fibers. As CMC and alginate are mixed in the spinning solution, the CMC can be uniformly dispersed in the alginate fibers. Photomicrographs of the alginate/CMC fibers showed a high degree of swelling when wet in saline (see Fig. 3).

Wicking of fluid

Alginate wound dressing is known to have the "gel blocking" properties whereby the fluid absorbed by the dressing does not spread along the fabric structure. Lateral wicking of fluid is difficult because the alginate fibers swell when on contact with wound exudates, and hence, the pore structures in the nonwoven structure are closed.

Figure 4 shows the photographs of fluid wicking when Sorbsan, Kaltostat, and Urgosorb dressings were placed in contact with 1.5% aqueous sodium citrate solution. It can be seen that for Sorbsan dressing, which has a loose nonwoven structure, even though the dressings quickly turned into a soft gel, the fluid was able to spread along the dressing to form a wet radius about 1.3 times the diameter of the original cup. The Kaltostat fibers were more difficult to gel and the wet radius was 1.5 times of the cup diameter, indicating the relatively poor gel blocking properties of the dressing. Urgosorb showed the best gel blocking properties, with the fluid virtually remaining on top of the plastic cup. Detailed results are listed in Table V.

Dry and wet strength

Table VI shows the dry and wet strength of Sorbsan, Kaltostat, and Urgosorb dressings. Because the Sorbsan dressings are made of loosely assembled fibers in a pressure rolled structure, the dry strength of the Sorbsan dressing is considerably lower than the other two dressings, which are both made of needled nonwoven structure. When placed in solution A, all the three types of alginate dressings had increased strength, most likely due to the adhesion of individual fibers when wet. Because of the high G nature of the alginate, the wet strength for the Kaltostat dressing is highest among the three dressings. The Urgosorb dressing had a lower wet strength than Kaltostat, most likely due to the disruption of the regular structure by the presence of CMC within the alginate fiber.

TABLE V
Test Results on the Wicking of Alginate/CMC and Other Alginate Dressings

	Wicking ratio
Urgosorb™	1.0
Sorbsan™	1.3
Kaltostat™	1.5

TABLE VI
Test Results on the Felt Strength of Alginate/CMC and Other Alginate Dressings

	Urgosorb™	Sorbsan™	Kaltostat™
Dry strength (N)	0.38 ± 0.06	0.13 ± 0.05	0.49 ± 0.07
Wet strength (N)	1.17 ± 0.18	0.81 ± 0.06	1.51 ± 0.41

CONCLUSIONS

This study has shown that the performances of the alginate wound dressings currently available on the market vary significantly from one type to another. They are affected by the guluronate and mannuronate contents of the alginate, the calcium and sodium contents of the fiber, the nonwoven structure, and the additives into alginate. High M alginate gels better than high G alginate. By introducing sodium ions or CMC into the alginate fibers, major improvements can be made on the absorbency of the alginate wound dressings.

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References

1. Speakman, J. B.; Chamberlain, N. H. J Soc Dyers Colourists 1944, 60, 264.
2. Turner, T. Wounds 1989, 1, 155.
3. Qin, Y.; Gilding, D. K. Med Device Tech 1996, 7, 32–41.
4. Thomas, S. Pharmaceutical J 1989, 243, 706.
5. Attwood, A. I. Br J of Plastic Surgery, 1989, 42, 373.
6. Groves, A. R.; Lawrence, J. C. Ann Royal Coll Surg Engl 1986, 68, 27.
7. Sayag, J.; Meaume, S.; Bohbot, S. J Wound Care 1996, 5, 357.
8. Onsoyen, E. In Thickening and Gelling Agents for Food; Imeson, A. Ed.; Blackie Academic and Professional: Glasgow, UK, 1992.
9. Qin, Y. J Appl Polym Sci 2004, 91, 953.
10. Qin, Y. J Appl Polym Sci 2004, 91, 1641.
11. British Pharmacopoeia Monograph for Alginate Dressings and Packings, 1994.
12. Moe, S.; Draget, K.; Skjak-Braek, G.; Smidsrod, O. In Food Polysaccharides and Their Applications; Stephen, A. M. Ed.; Marcel Dekker: New York, 1995; p 245.
13. Fenton, J. C.; Griffiths, B.; Mahoney, P. WO94/17227.
14. Franklin, K. J.; Bates, K. Brit. Pat. 1,375,572.
15. Miller, J. Brit. Pat. 1,328,088.
16. Wren, D. C. WO 90/01954.
17. Qin, Y.; Gilding, D. K. U.S. Pat 6,080,420.