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The Dynamic Film Thickness of Cushioning Agents on Contact Lens Materials

Using an in vitro technique, a number of commercial as well as pure polymer solutions were evaluated for their ability to form thick aqueous layers on contact lens materials. It was demonstrated that the thickness of adhered pure polymer films was strictly viscosity dependent and did not depend upon the solution's wetting properties (ie, contact angle and surface tension) nor the surface upon which the solution was deposited (eg, glass, a hydrophilic surface versus Plexiglass, a relatively hydrophobic surface). The clinical implications of this study are that the desired solution properties of tear substitutes may be quite different from those of wetting and "cushioning" solutions.

Introduction

The rationale behind the use of polymer solutions in commonly employed contact lens practices is for their use as wetting, cleaning, and cushioning agents. Since the most commonly used plastic for the manufacture of hard contact lenses, polymethylmethacrylate, (Plexiglass) is relatively hydrophobic compared to glass, polymer solutions should have the capability of completely wetting such

a plastic to ensure a good refractive surface and the necessary lubrication between the palpebral conjunctiva, the lens, and the corneal surface. The wetting of a solid by a liquid may be simply defined as the ability of the liquid to spontaneously spread on the solid. In physical terms, the adhesive forces between the solid and liquid causing the liquid to spread must be greater than the cohesive forces of the liquid causing the liquid to contract on the solid surface. The wetting of the corneal epithelium (believed to be a hydrophobic surface) by normal tears is accomplished by two processes[1]: (1) mucin, produced by the goblet cells of the conjunctiva, is spread by the eyelids and is loosely adsorbed to the corneal epithelium causing the sur-

face to become more hydrophilic, and (2) the superficial meibomian lipid film at the air/tear interface decreases the surface tension of the tear, allowing for more complete wetting of epithelium. The same processes might be expected to produce wetting of a contact lens when it is placed on the ocular surface. However, this process probably does not occur immediately. In order to reduce the initial discomfort or "lens awareness" while this process is taking place, a number of commercial solutions have been formulated to act as "cushioning agents." The "cushioning" property of a polymer solution, which may or may not be related to its wetting properties, is a vague term used to describe the production of a continuous, thick film over the surface of a contact lens by a polymer solution. Polymer solutions used as "cushioning agents" have been shown to increase the level of comfort for contact lens wearers.[2-5]

In this study, the effects of surface tension, viscosity, contact angle, and the polymer type of various polymer solutions were examined for their influence on the ability of solutions to form a thick continuous film on the artificial surfaces of glass and Plexiglass. All of these properties could conceivably affect the formation of a film over a solid surface.

Materials and Methods

Polymer Solutions Hydroxypropylmethylcellulose (HPMC) (Methocel 65 HG 4000 cp) was obtained from Barnes-Hind Pharmaceuticals, Inc., polyvinyl alcohol (PVA) (Cat. No. 4396) acetate content 12% was obtained from Polysciences, Inc., and methylcellulose 1500 (MC-1500) from Fisher Scientific, Inc. All commercial solutions were obtained from their respective manufacturers: Barnes-Hind Wetting Solution, One Solution, Lyteers (Barnes-Hind Pharmaceuticals, Inc.), Adapt, Flexsol (Burton-Parson and Co., Inc.), Lacril, Liquifilm, Presert (Allergan Pharmaceuticals), Visculose, Methulose (Professional Pharmacal Co.), and Isoptoplain (Alcon Laboratories Inc.).

All dry polymers were added at room temperature to a 0.9% NaCl solution made with double distilled water from an all glass still and stirred with a magnetic stirrer until dissolved. The viscosity (η) of all solutions was measured with a Brookfield Synchrolectric viscometer. A Rame-Hart contact goniometer was used to measure the advancing contact angle (θ) of solutions at equilibrium (approximately 3 to 5 minutes after drop deposited) and a Honeywell pressure transducer was used to measure surface tension (γ) by the Wilhemy plate method. The contact angle is the angle formed between the edge of a drop of liquid and the surface upon which the drop is placed and is a measure of a solution's wetting ability. For example, water completely wets glass which is a hydrophilic surface and consequently the contact angle is zero. Water will not completely wet Plexiglass and forms a contact angle of 65°. A solution is said not to wet at all if its contact angle is greater than 90°. Solutions with contact angles below 90° are said to wet incompletely. Under dynamic conditions, solutions with contact angles less than 90° can form a continuous liquid layer on some solid surfaces.

The thickness of the polymer film deposited on glass or Plexiglass was measured in the following manner. A slide of glass or Plexiglass (7 x 3 cm) was attached by a clip to a rigid vertical rod which was moved up and down by an electric motor. The slide was then dipped at a constant speed (1 cm/sec) into a beaker containing the polymer solution in question. The slide was dipped 4 times and allowed to drain for one minute. The bulk solution was then blotted from the bottom of the draining side with

filter paper for 5 seconds. The slide was then weighed on a Sartorius balance (accurate to 0.1 mg). The average thickness* of the deposited film, the dynamic film thickness, was determined by dividing the volume of the solution (ie, weight of adhered solution/density of solution) by the surface area of the film (ie, surface area of the slide covered by the film).

Results

Studies on Experimental Methods

In order to determine the accuracy of the method for measuring the thickness of deposited polymer films described above, 10 glass slides were dipped into a solution of MC-1500 having a viscosity of 125 cp, weighed and the dynamic film thicknesses were calculated. The thickness of the films deposited on each of the 10 slides ranged from $86.8\mu m$ to $92.9\mu m$ with a mean of $89.6\mu m$. For a low viscosity solution (MC-1500, 25 cp), the range was $30.8\mu m$ to $32.9\mu m$ with a mean of $31.5\mu m$. A 5 second blotting time was sufficient to remove most of the bulk solution which had drained to the bottom of the vertical slide after it was dipped into the polymer solution. This time was determined by demonstrating that the difference in the calculated film thickness on a slide which had not been blotted and one which had been blotted for 5 seconds was 40% for both 125 cp and 25 cp viscosity solutions of MC 1500. The change in thickness beyond a 5 second blotting time (10,20,30 seconds blotting time) was a constant 10% for the same solutions.

Thickness of Adhered Polymer Films

Figure 1, A and B, depicts the thickness of the layers of polymer solutions ad-

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*Recently we compared (unpublished) the average thickness measured by weighing technique with that obtained from fluorescence measurement in which case the polymer solution contained fluorescein. Both methods gave identivcal values for film thickness within experimental limit ($\pm 0.5\mu m$).

hered to glass and Plexiglass respectively as a function of their viscosity. It can be seen that there is a trend toward increasing film thickness with increasing viscosity, regardless of the polymer, commercial solution, and the surface upon which it is deposited, glass (hydrophilic) or Plexiglass (relatively hydrophobic). It also can be seen that at the same viscosity HPMC and MC 1500 produce considerably thicker films than PVA.

Figure 2,A demonstrates that for the commercial solutions there seems to be a relationship between thickness and surface tension. Solutions with a lower surface tension produce thicker films. However, if the prepared solutions of HPMC, MC-1500, and PVA all at 75 cp viscosity are considered, the relationship between surface tension and thickness does not seem to strictly apply.

Figure 2,B reveals that there is no correlation between the film thickness formed on glass and Plexiglass and the contact angles of the solutions on the same surfaces.

There were a few commercial solutions that did not produce a continuous film on Plexiglass or glass surfaces. The following solutions produced discontinuous films on Plexiglass: Adapt ($\eta = 70$ cp, $\gamma = 50, \theta = 56°$), Lyteers ($\eta = 10, \gamma = 31, \theta = 40°$). The following solutions produced discontinuous films on glass: Visculose ($\eta = 130, \gamma = 23, \theta = 20°$), Methulose ($\eta = 12, \gamma = 39, \theta = 11°$), Lyteers ($\eta = 19, \gamma = 31, \theta = 14°$). It is appropriate at this point to explain exactly what we mean by discontinuous since not all of the polymer films became discontinuous in the same manner or to the same degree. Referring to those solutions which were discontinuous on Plexiglass, immediately upon the emergence of the slide from a solution of Adapt, the film receded from all edges to the center of the slide in 5 to 10 seconds, leaving the slide completely dry. The
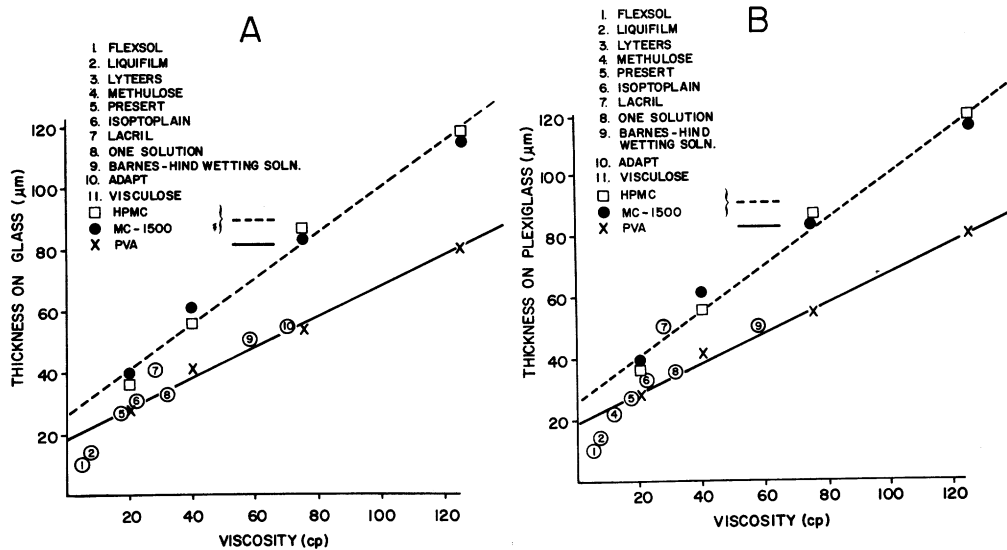
FIG 1. (A) The dynamic film thickness of polymer solutions on glass as a function of their viscosity. (B) The dynamic film thickness of polymer solutions on Plexiglass as a function of their viscosity.

discontinuity of the film formed by Lyteers was not as dramatic, in that small dry holes appeared in the center of the coated slide and did not enlarge over a period of 10 to 15 seconds to more than 2 to 3 mm in diameter. With reference to the solutions that produced discontinuous layers on glass, Lyteers followed the pattern of Adapt on Plexiglass in that there was a rapid recession of the film from all edges to the center of the slide in 5 to 10 seconds. Methulose and Viscu-

lose resembled one another in their pattern which was as follows. The film receded from the edge but very slowly compared to Adapt on Plexiglass and Lyteers on glass. Dry areas appeared on the edge of the slide within 5 to 10 seconds but did not reced more than 2 to 3 mm in 1 minute.

Comment

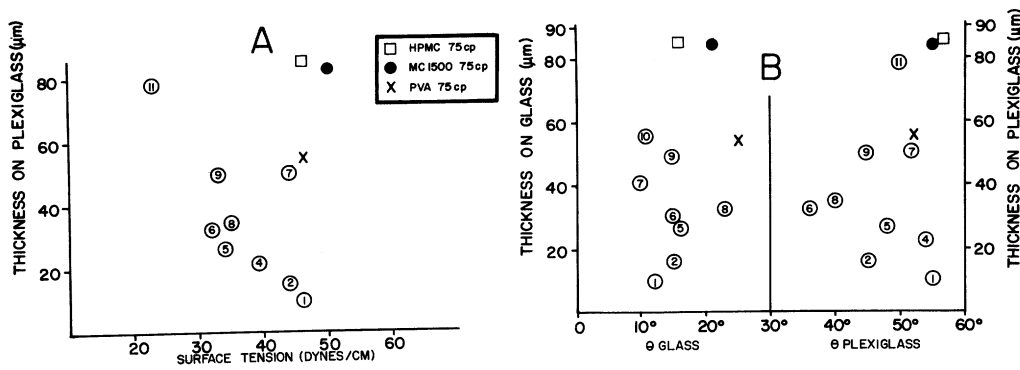In the past there has been some concern about the measurement of the

FIG 2. (A) The dynamic film thickness of polymer solutions on Plexiglass as a function of their surface tension. (B) The dynamic film thickness of polymer solutions on glass or Plexiglass as a function of their contact angle on glass or Plexiglass.

contact angle and surface tension of polymer solutions on the assumption that a solution with a low surface tension and a small contact angle will have the best wetting properties on a contact lens as well as the ocular surface. We have demonstrated that over a wide range of contact angles and surface tensions, as well as on two surfaces, one completely hydrophilic and the other relatively hydrophobic, that practically all of the solutions tested produced continuous films on these surfaces. Furthermore, that the dynamic thickness of the film produced is independent of the surface upon which it is deposited and is more directly proportional to the viscosity of pure polymer solution. Some polymer solutions produced discontinuous films on either glass or Plexiglass. There did not seem to be any reason for their discontinuity on the basis of their surface tension or contact angle, indicating that some solution component or combination of components not appreciably affecting these parameters, might be responsible for their discontinuity. However, we would like to emphasize that at this stage, extrapolation of this fact to clinical relevance is guarded since there has not been any clinical study correlating film discontinuity on contact lenses with decreased patient comfort.

It might be said that surface tension and contact angle are not critical properties in determining film continuity or dynamic film thickness at such great thicknesses as those studied by the dipping technique described. However, it should be emphasized that the thicknesses measured are average thicknesses and that at the top of a vertically hanging slide the film thicknesses are probably considerably less. A thick layer of water (hundreds of μm) will form a continuous film on a hydrophobic surface,[6] but at a thickness below a critical value the film will rupture. It is interesting to note that Flexsol has a contact angle of 55° on Plexi-

glass as compared to the contact angle of 65° for pure water and still forms a continuous film with an average thickness of only 10μ on Plexiglass, whereas, water does not adhere at all to Plexiglass. It is hard to escape the conclusion that the components of polymer solutions, probably the polymer molecules themselves, in some way, are acting to stabilize these thin films in much the same way as mucin does on the corneal epithelium as suggested by Holly and Lemp.[1,7] We believe that the polymer molecules may be loosely adsorbing to the solid surface, and hence anchoring the aqueous layer to the solid surface without significantly influencing the contact angle.

The above considerations indicate that when speaking of the wetting of solid surfaces by polymer solutions the contact angle is probably not the most important factor. Contact angle as a measure of wetting of a solid by a liquid should theoretically only be applied to pure liquids and to polymer or surfactant solutions with some reservations. This study indicates that viscosity is the most important property of a polymer solution determining the "cushioning" layer (dynamic thickness of the film) that the solution will form on a solid surface. However, our previous study[8] indicates that the spreading properties of polymer solutions are a more important determinant of the thickness of the films produced by polymer solutions on the ocular surface.

These studies have some important clinical implications in that a solution should have good spreading properties if it is to be used as a tear substitute but should have a high enough viscosity to form a thick adsorbed film if it is to be used as a cushioning agent. However, the undesirable properties of highly viscous polymer solutions, eg, ocular discomfort, lid crusting, and impairment of tear circulation between the lens and the corneal surface should also be minimized.

We would like to emphasize that the dynamic film thickness probably only bears a relation to the thickness at time zero after the application of a polymer coated lens to the ocular surface. The dynamic film thickness as measured in this study tells nothing of the desorption kinetics of polymer molecules from the coated lens which should be an interesting area for future investigations.

Acknowledgment

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