How Do Tears Exit?
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The mechanisms of tear flow, blinking, and tear drainage were studied employing high speed slit-lamp cinematography using a polystyrene microsphere suspension as a tracer of tear movement. It was demonstrated that: (1) Tears are drawn into the canaliculi during the relaxation phase of blinking. (2) Both superior and inferior puncta function as normal tear drainage routes. (3) The superior punctum alone is sufficient to handle tear drainage. (4) There is some regurgitation of tears from the canaliculi. (5) An intact blink mechanism is necessary for effective tear drainage. (6) There is an actual closure of the puncta during blinking. This is sufficient to effect tear exit without the lids meeting. The clinical impression that in order to effectively prevent tear drainage in the treatment of dry eyes, it is necessary to occlude both the superior and inferior puncta was confirmed. Invest Ophthalmol Vis Sci 24:619–622, 1983

The mechanisms by which tears exit from the conjunctival sac into the tear drainage system consisting of the puncta, canaliculi, lacrimal sac, and nasolacrimal duct have been a subject of some debate for many years. Various theories have been advanced to account for this smoothly functioning exit pathway. Early studies indicated that tears drain effectively even without the effect of gravity, ie, when the head is inverted. Two basic theories of tear drainage subsequently evolved. One theory, based on anatomical studies, suggested that a pressure rise in the conjunctival sac at the moment of lid closure produces a positive driving force pushing tears into the puncta and through a passive drainage system. In contrast, is the so-called "lacrimal pump" theory of Jones, which postulates a muscular compression of the canaliculi and probable expansion of the lacrimal sac during lid closure, creating a negative pressure with tears then being drawn through the entire pathway into the nose.

Earlier studies by Frieberg and Rosengren and more recent studies by Maurice and Wright have substantiated the active nature of tear drainage. The studies of Frieberg and Rosengren employed cannulation of the nasolacrimal duct and lacrimal sac; they measured pressure changes during blinking and concluded that tear drainage was due primarily to a compression of the canaliculi by muscular contractions associated with blinking. More recent studies have confirmed pressure changes in the canaliculi associated with blinking. These studies have noted a pressure rise within the lacrimal sac associated with blinking; this is consistent with a contraction of the sac rather than an expansion as suggested by Jones. A recent report by Chavis et al employing quantitative lacrimal scintillography proposed a bimodal theory: the canaliculi and, possibly, the sac are active in fluid movement into the sac, but flow from the sac throughout the nasal lacrimal duct is passive. A passive or at least nonessential role of the sac is suggested by the clinical observation that tear drainage is unimpaired after extirpation of the sac, ie, dacryocystorhinostomy.

Doane in a recent paper developed a sophisticated high speed photographic apparatus employing frame speeds of up to 500 per second; he has confirmed many of the basic aspects of the tear drainage process as elucidated by Frieberg and Rosengren. He has also noted that the punctal openings elevate themselves from the lid margin at the beginning of the blink allowing their forceful meeting and occlusion about the time the closing lid is halfway down. It is concluded that completion of the lid closure compresses the canaliculi and lacrimal sac forcing the contained fluid through the drainage system. Doane continues that the elastic expansion of the canaliculi during the opening phase of the blink forms a suction holding the lid margins at the punctal region together as the lids open. Subsequently the punctal areas seem to pop apart as the vacuum is broken and tear fluid from the marginal tear strip is drawn into the puncta the first few seconds following a blink.
Materials and Methods

We have employed a slit lamp fitted with a continuous 150 watt high pressure Zenon arc light source manufactured by Carl Zeiss. A Beaulieu 16-mm camera is attached to the slit lamp via a beam splitter (Fig. 1). Frame speeds of up to 64 frames per second were used; Kodak 7242 high speed ASA 125 color film was used throughout the studies; the film was processed by Kodak ME-4 process. The approximate effective exposure time for each frame was 1/80th of a second. Magnification of the slit-lamp images was varied. The developed film was subjected to forward and reverse analysis using a LW cine image analyzer at speeds as low as one frame per second.

This method differs from that of Doane in the following respects: (1) Filming speed is slower in this method (64 frames/second vs 500 frames/second). This speed was found to be sufficient to analyze both tear flow and lid movement. (2) Our light source and lens were closer to the subject, causing some initial reflex tearing. There was, however, a rapid adjustment to the intensity of this light source; clinical tearing and photophobia were absent after approximately 2 min of exposure. (3) The ease of varying magnification of the slit lamp and the use of high magnification without a loss of resolution with a closer lens allows for observation of small fleeting phenomena in great detail eg, punctal closure.

Black polystyrene microspheres measuring approximately 15 microns in diameter (Minnesota Mining & Manufacturing Co.) were mixed into a suspension in an artificial tear solution and instilled into the conjunctival sac. As these microspheres are instilled, many of them are taken up by the surface mucin network of the conjunctiva (Fig. 2). These accumulate into the rather viscous thick mucin thread frequently seen in the inferior cul-de-sac; however, a significant number of these remain in suspension and are seen along the marginal tear strip. They can be seen both along the inferior and superior tear strips. Their movement can be studied with high speed cinematography and subjected to analysis. We studied a series of ten normal subjects and three patients with abnormal blinking patterns.

Results

It is apparent that there is a to-and-fro movement of spheres over the inferior and superior puncta during blinking. Multiple spheres can be seen to rush into the puncta immediately upon completion of the blink confirming negative pressures created within the canaliculi. This movement can be seen into both inferior and superior puncta. The drainage mechanism is, however, not 100% efficient. There is some regurgitation of these spheres after an initial entry. Moreover, with a slight overloading of the conjunctival sac and a fullness to the marginal tear strip, a bidirectional flow is seen in the inferior strip; this fact was noted earlier by Maurice. The predominant direction of flow, however, is nasally toward the punctum. Krebliel flow as described by Maurice and Doane is seen, particularly with an overload of the conjunctival sac. Some of this flow crosses the inferior punctum, over the caruncle and up into the superior punctum. The superior punctum clearly acts as both a normal exit pathway and also as an overflow drainage mechanism.

The relative roles of the superior and inferior
Fig. 3. Individual frame photographs at 1/64th of a second of 16 mm cine film strip. A, Inferior punctum open (arrow). B, Inferior punctal closure (arrow) associated with blinking.
puncta can be studied by either occluding one punctum or studying patients in whom this is a permanent condition. In one subject we used the Freeman punctal plug and studied the tear exit with microspheres in these circumstances. It is clear that the superior punctum can function normally and take up the extra drainage temporarily occluded by the punctal plug in the inferior punctum. In a subsequent study of the patient with congenital atresia of the inferior puncta, similar results with perfectly normal drainage through the superior punctum were noted. This patient also had the confirmatory clinical evidence of a lack of epiphora despite the absence of an inferior punctum. These studies have lead us to conclude that if an attempt is made to occlude puncta in order to preserve tears in the treatment of dry eyes, it is necessary to occlude both the superior and inferior puncta. This confirms the clinical observation made by Dohlman and the previous studies by Jones et al.

Our studies have confirmed those of Doane in which he suggests that the average duration time for a normal blink is about 0.08 seconds (4 frames at 64 per second). We have also confirmed his description of the initial elevation of the puncta and the fact that in most subjects the two puncta seem to meet by the time the lid is about half way closed. Our results, however, differ in that we have found that the puncta do not necessarily "kiss" in all subjects and that, indeed, with a forced blink there is a frequent sliding of the inferior punctum nasally beyond the area where it meets the superior punctum. In a study in which we slightly everted the lower lid, it can be seen easily that there is an actual closure of the puncta (Fig. 3) that occurs in both the superior and inferior puncta and is not dependent upon the actual meeting of the two puncta to effect closure. In fact, tear flow into the lower punctum without the lids approximating on a blink can be demonstrated, indicating that the actual mechanism resides within the punctum and/or canaliculus, and it is not dependent on the actual physical meeting of the lid margins. Analysis of these films of punctal closure also shows evidence of compression of the canaliculus during the same time period.

Confirmatory evidence in a patient studied with congenital atresia of the inferior puncta, yet with normal tear drainage also confirms that the two puncta do not necessarily meet to effect tear drainage.

Discussion

Our studies have elucidated further some of the mechanisms involved in drainage of tears. They support the presence of an active mechanism dependent upon normal blinking for effective tear drainage. These studies are in general agreement with those of Doane, with the exception that we have found that it is not necessary for the two puncta to actually meet in order to effect tear drainage. This closure of the puncta and canaliculi is apparently effected by muscular action of the lids during blinking. The necessity of an effective blinking mechanism was dramatically demonstrated in a lack of directional flow towards the puncta in a patient with paralysis of the orbicularis muscle; there was simply a random movement of microspheres in the lacrimal river with an ineffective attempt at lid closure. We have also demonstrated the efficacy of the superior or inferior puncta acting as sufficient drainage mechanism for the tears.

On the basis of these studies, we conclude that in order to eliminate effectively tear drainage, occlusion of both puncta is necessary. Further studies using the same type of apparatus should help us further elucidate some of the pathophysiology in various abnormal conditions involving the lids and lacrimal excretory structures.

Key words: tears, lacrimal drainage, blinking, puncta, lid closure

References